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COMPARISONS OF FLIGHT TO GROUND-BASED PILOT-INDUCED OSCILLATION EVALUATION METHODS

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13. ABSTRACT *(Maximum 200 words)*

This report documents comparisons of flight and ground-based Pilot-Induced Oscillation (PIO) evaluation methods. The study was to develop and modify ground-based simulation methods to improve the likelihood of early PIO detection. The study strickly looked into the linear causes of longitudinal PIOs due to phase lag or high time delays as opposed to nonlinear PIO types such as rate limiting or mode switching. The results of the ground-based simulation were compared with data taken from the HAVE PIO flight test program. The flight test program was well documented and provided a good basis from which to establish a ground simulation. The PIO tendencies of flight test configurations ranged from none to severe. The wide range of PIO tendencies was important to preclude an evaluation process wich would result in false PIO predictions. Comparisons were based on Cooper-Harper and PIO ratings which were validated by time history data and pilot comments. Trends were established which led to several proposed evaluation concept such adding gates at the offset corrections, time delays, and winds, gusts and turbulence to the model, and increasing pilot stick gain to make ground-base simulators a more effective tool for detecting PIO.

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1. INTRODUCTION

Pilot-Induced Oscillation (PIO) is a very complicated phenomenon stemming from a dynamic interaction between the pilot and aircraft. An aircraft can be otherwise well behaved and the pilot can be well trained; however, when tight interaction between the pilot and aircraft is required, under some situations an undesired oscillation can result.

A recent excellent example of PIO was the crash of the Lockheed/Boeing YF-22A Advanced Tactical Fighter prototype, which shows how a precision tracking task can lead to a PIO. Several changes occurred simultaneously in the aircraft dynamics and flight control laws. According to Reference [1], the fundamental triggering mechanism for the YF-22 PIO was the large command gradient change at the gear-down and gear-up mode transition. During the mode transition, the pilot applied a considerable amount of nose-up trim, which forced him to operate near the forward deflection limits of the pitch stick for level flight. With the thrust vectoring engaged, the flight control laws allowed the pilot to command much larger pitch rates gear-up than gear-down. This resulted in an unpredictable response and a PIO.

Most existing PIO analysis methods and criteria were developed to address individual effects. These criteria typically do not include non-linearities which can have a significant impact on flying qualities and PIO susceptibility. This AFRL Unified PIO program [2,3,4,5] is meant to develop a comprehensive unified theory which predicts and eliminates both linear and nonlinear causes of PIO. The approach of the Unified PIO program includes design criteria, piloted simulation evaluation, and an on-board PIO detector.

Ground-based simulators have become an indispensable tool in the development of modern aircraft due to the reduction of funds available for prototyping and the increased complexity of modern aircraft flight systems. By providing piloted evaluations of aircraft flying qualities long before the aircraft is ready to fly, simulators allow designers to detect problems, redesign, and re-evaluate aircraft early in the design process. This is an enormous advantage, since flight control fixes become more expensive and have greater impacts on schedule as the development process continues. For PIOs, however, experience has shown that ground-based simulation has not been particularly successful at detecting problems prior to flight test. This is due partly to the adaptive nature of the human pilot. It should be noted that in many programs, PIOs encountered in flight test have been subsequently duplicated in the simulator. This gives some confidence that prediction of PIOs in early simulation may be possible.

The effort reported here is an attempt to improve the process used to define and implement the evaluation of PIO on a ground-based simulator. In particular, the known differences between flight and simulation such as stick sensitivity and pilot gain, are directly addressed. A 'truth model' is available in the HAVE PIO flight test [6] study reported by AFFTC, and Capt. Eileen A. Bjorkman's Masters Thesis [7]. Means of establishing a 'trigger' are defined. And all the reasons why our approaches failed are discussed. But this is an interim report and all of the lessons learned to date will be applied in an effort to achieve the original objectives.

1.1 Objectives

This report documents the results of the HAVE PIO in-house research program. The purpose of the study was to develop and modify ground-based simulation methods to improve the likelihood of early PIO detection. This phase of the study strictly looked into the linear causes of longitudinal PIOs due to phase lags or high time delays as opposed to nonlinear PIO causes such as rate limiting or mode switching. The results of the ground simulation were compared to data taken from the HAVE PIO flight test program. The flight test was well documented and provided a good basis from which to establish a ground simulation evaluation. In this flight test program, 18 configurations were flown in the landing phase on the NT-33A variable-stability aircraft. The dynamics of these configurations ranged from solid Level 1 to Level 3 aircraft flying qualities. The PIO tendencies of these configurations ranged from none to severe. The wide range of PIO tendencies was important to preclude an evaluation process, which would result in false PIO predictions. Comparisons were based on Cooper-Harper (CH) and PIO ratings [8], time history data and pilot comments. Trends were established which led to several proposed evaluation concepts to make ground-based simulators a more effective tool for detecting PIO.

1.2 Approach

The effort consisted of two phases. In Phase I, the flight test model was implemented in several simulators in accordance with best engineering practice. Results from Phase I were used to establish a baseline comparison between ground-based simulation and flight. Phase II made changes to the simulation to improve the correlation with flight results. The changes were an attempt to increase the pilots' gain and to expose the handling quality deficiencies. These changes were: a) Adding gates at the offset and at the final approach locations to emphasize the change from a lateral task to a longitudinal task and to increase task difficulty. Increasing the lateral offset distance and shortening the distance between the two sets of gates made the task harder for the pilots to fly. b) Improving pilot visual cues during the touchdown by adding two pairs of horizontal pylons on both sides of the runway. This helped the pilots reduce their touchdown dispersions. Another set of pylons was placed vertically on either side of the runway in alignment with the touchdown point. These vertical pylons helped the pilots to improve their sink rates at the touchdown. c) Several levels of time delay were added into the model to artificially compensate for the pilots apparent increased tolerance to phase lag in the simulator. d) The stick sensitivity was changed. e) The winds, gusts and turbulence were also added into the model to increase the task difficulty.

The 18 configurations of the HAVE PIO flight test program were implemented and evaluated on different ground-based simulators in various levels of sophistication. Different levels of simulator sophistications represented the real applications of an aircraft design process. Each simulation platform would represent its own characteristics in terms of predicting PIO in flight.

Four simulation platforms [9] were used in the study.

a,b) <u>Large Amplitude Multi-Mode Aerospace Research Simulator (LAMARS)</u> -

LAMARS is a motion-based, 20-ft dome with two side projectors, each with a 40.5°x30° FOV, and a center projector with a 45°x30° FOV. The total FOV is 135° without gaps. Table 1 shows the LAMARS specifications.

Out-the-window scenery was generated with the General Electric Compuscene IVA. The visual time delay for PIO simulation using LAMARS was 90 ms. The difference in time delay from MS-1 was due to the relative synchronization between the simulations and the image generator. Both center and side stick can be implemented in the LAMARS cockpit, however, a center stick was used for this program. LAMARS was run in both a motion and a fixed-base mode.

Table 1: LAMARS and MS-1 Specifications

	MS-1	MS-1	LAMARS
	Background	Area of Interest	
Resolution	11 arc min./line	2.5 arc min./line	9 arc min/line horizontal 11 arc min./line vertical
Contrast	4:1	7:1	17:1
Luminance	0.15 ft-lamberts	0.30 ft-lamberts	0.34 ft-lamberts
Refresh rate	30 Hz interlaced (60 Hz field rate)	30 Hz interlaced (60 Hz field rate)	30 Hz interlaced (60 Hz field rate)

c) <u>Mission Simulator-1 (MS-1)</u>

MS-1 is a fixed-based, 40-ft dome with a 180° field of view (FOV) with a high-resolution area of interest (AOI) which has a 40° FOV. Table 1 shows the specifications for the background and AOI.

Out-the-window scenery was generated with a General Electric Compuscene IVA with two high-resolution channels, which can be broken down into six low-resolution channels. It is capable of displaying two million pixels and 4096 polygons. The measured time delay for the PIO simulation using MS-1 was 75ms. The time delay of interest was the delay from when a change occurred in a simulation state variable until that change was observed on the out-the-window display. Delays due to input sampling and the model were not included in this measurement. The Simulation Network Analysis Project (SNAP) tool, designed by engineers at the Control Integration and Assessment Branch, was used to make these measurements. This tool is capable

of collecting and accurately time sampling analog, digital, and ethernet data. In addition, it has the unique capability of determining roll and pitch angles of a displayed horizon from a display's video signal. The test consisted of toggling the simulation pitch angle between two discrete values and then measuring the time from when the pitch angle changed until that change was observed in the video signal going to the projectors.

d) Manned Combat Station (MCS)

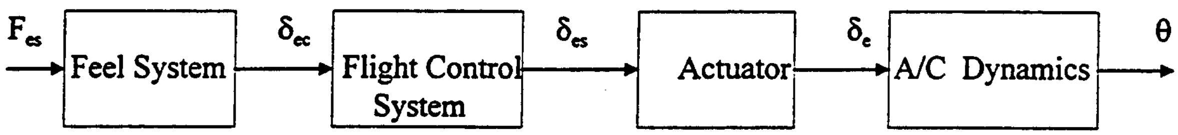
MCS is the simplest simulator set up among our simulators. This set up mostly represents an engineering analysis tool for use when one cannot afford to have a fully capable simulation. The system usually has a small monitor, a stick and a throttle and is typically hosted on a PC or a workstation. The key elements, which degrade the flying quality assessment, are the lack of field of view and the pilot vehicle interface issues.

2. FLIGHT TEST SYSTEM DESCRIPTION

The HAVE PIO flight test program was the AFTPS project of Capt. Eileen Bjorkman's Master's Thesis in 1986. This flight test program evaluated 18 configurations in landing tasks. Landing longitudinal PIO tendencies and flying qualities were evaluated using four sets of short period natural frequency and damping ratio and applying some of the 14 different flight control system configurations to various combinations in that set. These configurations examined only linear causes of PIO such as a high time delay due to phase lag in the model. Non-linear causes of PIO were not included in this study. With the exception of the configuration 3-1, the short period dynamics of the base line configurations met MIL-STD-1797A Level 1 boundaries for the landing approach (Category C).

2.1 Longitudinal Characteristics

The following block diagram shows the longitudinal elements of the system.



The longitudinal feel system dynamics are:

$$\frac{\delta_{ec}}{F_{es}} = \frac{0.125(26^2)}{\left(s^2 + 2(0.6)(26)s + 26^2\right)} \text{ (in/lb)}$$

Various types of flight control system were used. The following equation represents first-order flight control system:

$$\frac{\delta_{es}}{\delta_{ec}} = \frac{K(s+\tau_1)}{(s+\tau_2)} \text{ (deg./in)} \quad \text{or} \quad \frac{K}{(s+\tau_3)} \text{ (deg./in)}$$

The 18 configurations were based on four sets of aircraft dynamics modified with various lag or lead/lag flight control system. Table 2 gives the parameters for these flight control systems. The labeling convention (e.g. 3-6) assigns the first number to the corresponding set of baseline aircraft dynamics. The second number or letter corresponds to the flight control system. The flight control system for configurations 2-1, 3-1, 4-1, and 5-1 are unity gain with no dynamics.

Table 2: HAVE PIO 1st - Order Flight Control System

	-B	-D	-1	-2	-3	-5
K	3.0	0.5	1.0	10.0	4.0	1.0
τ_1	3.33	20.0	---	---	---	---
τ_2	10.0	10.0	---	---	---	---
τ_3	---	---	---	10.0	4.0	1.0

The following two equations represent second and fourth-order flight control system respectively.

2nd Order: $$\frac{\delta_{es}}{\delta_{ec}} = \frac{K}{\left(s^2 + 2\zeta_1\omega_{n1}s + \omega_{n1}^2\right)} \quad \text{(deg./in)}$$

4th Order: $$\frac{\delta_{es}}{\delta_{ec}} = \frac{K}{\left(s^2 + 2\zeta_1\omega_{n1}s + \omega_{n1}^2\right)\left(s^2 + 2\zeta_2\omega_{n2}s + \omega_{n2}^2\right)} \quad \text{(deg./in)}$$

Table 3 lists the values of the various parameters of the second- and fourth-order flight control system.

Table 3: HAVE PIO 2nd-and 4th-Order Flight Control Systems

	-6	-7	-8	-9	-10	-11	-12	-13	
K		16^2	12^2	9^2	6^2	4^2	16^4	2^2	3^2
ζ_1		0.7	0.7	0.7	0.7	0.7	.93	0.7	0.7
ω_{n1}		16	12	9	6	4	16	2	3
ζ_2		---	---	---	---	---	.38	---	---
ω_{n2}		---	---	---	---	---	16	---	---

The following actuator transfer function is used for all 18 configurations:

$$\frac{\delta_e}{\delta_{es}} = \frac{75^2}{\left(s^2 + 2(0.7)(75)s + 75^2\right)} \quad \text{(deg./deg.)}$$

The longitudinal aircraft transfer function has the following form

$$\frac{\theta}{\delta_e} = \frac{K_\theta\left(s+1/T_{\theta 1}\right)\left(s+1/T_{\theta 2}\right)}{\left(s^2+2\zeta_p\omega_p s+\omega_p^2\right)\left(s^2+2\zeta_{sp}\omega_{sp} s+\omega_{sp}^2\right)}$$

The four sets of the baseline aircraft dynamics are shown in Table 4.

Table 4: HAVE PIO Longitudinal Dynamics

Parameters	Configurations			
	2 - x	3 - x	4 - x	5 - x
$T_{\theta 1}$	12	12	12	12
$T_{\theta 2}$	1.4	1.4	1.4	1.4
ζ_{sp}	0.64	1.0	0.74	0.68
ω_{sp}	2.4	4.1	3.0	1.7
ζ_p	0.15	0.17	0,.16	0.16
ω_p	0.17	0.16	0.16	0.15

The values of $T_{\theta 1}$ and $T_{\theta 2}$ were the same for all configurations. The final parameter required for the configuration definition is K_θ. The K_θ is a function of the ratio of elevator to stick deflections, described in Reference [6,7]. During flight test, the K_θ was called as the "gearing" and was selected for each configuration by the first pilot to fly it; on subsequent evaluations the gearing remained set at the value initially selected. The values of K_θ of the four baseline configurations are shown in the flight pilot comment cards of Appendix A.

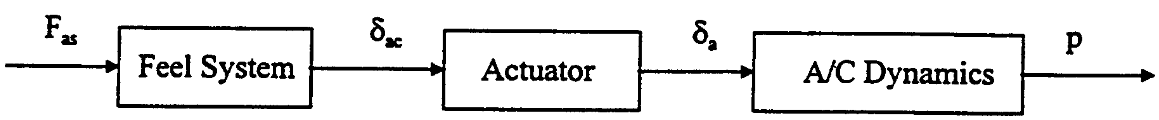
The combinations of aircraft dynamics and various flight control systems represented in the 18 configurations are shown in Table 5.

Table 5: A/C Dynamics with Flight Control Systems

Filter	Configuration			
	2 - x	3 - x	4 - x	5 - x
-B	X			
-D		X		
-1	X	X	X	X
-2			X	
-3		X		
-5	X			
-6		X		
-7	X			
-8	X	X		
-9				X
-10				X
-11				X
-12		X		
-13		X		

2.2 Lateral/Directional Characteristics:

The following block diagrams show the lateral/directional system elements. The lateral-directional feel system dynamics are:



Lateral: $$\frac{\delta_{ac}}{F_{as}} = \frac{0.25(26^2)}{\left(s^2 + 2(0.7)(26)s + 26^2\right)} \text{ (in/lb)}$$

Directional: $$\frac{\delta_{rp}}{F_{rp}} = \frac{0.017(26^2)}{\left(s^2 + 2(0.7)(26)s + 26^2\right)} \text{ (in/lb)}$$

The actuator model for the lateral-directional axes is the same one used for the longitudinal case:

$$\frac{\delta_a}{\delta_{ac}} = \frac{\delta_r}{\delta_{rp}} = \frac{75^2}{\left(s^2 + 2(0.7)(75)s + 75^2\right)} \text{ (deg/in)}$$

Lateral-directional dynamics are the same for each configuration. The modal characteristics are shown below.

$\omega_d \approx \omega_\phi \approx 1.3$ rad/sec

$\zeta_d \approx \zeta_\phi \approx 0.2$

$\left| \phi / \beta \right|_d \approx 1.5$

$\tau_r \approx 0.3$ sec

$\tau_s \approx 75$ sec

$N'_{\delta r} \approx -0.2 \frac{\text{rad/sec}^2}{\text{in}}$

$L'_{\delta a} \approx 0.7 \frac{\text{rad/sec}^2}{\text{in}}$

The longitudinal characteristics of flight model in fixed stability derivatives are shown in Appendix B.

2.3 Evaluation Task

A landing task was evaluated in flight. The landing task was defined to maximize repeatability of the results. A long look technique [10] was used during the landing task in flight. Each pilot flew at least three approaches for each configuration; a straight in approach followed by two offset approaches, one to each side of the runway. After making three approaches, the project pilot assigned both PIO and Cooper-Harper ratings as a measure of PIO tendency, performance and pilot workload. In the flight test program, for the landing task, a PIO was defined as a sustained oscillation, which interfered with the accomplishment of the task and required the pilot to reduce his gain or remove himself from the loop. A PIO tendency was defined as an undesirable motion, which did not necessarily interfere with the accomplishment of the task.

The offset landing task for this project was a visual approach with a lateral offset and a correction to centerline of the runway prior to touchdown. Figure 1 depicts the runway landing task of flight test. The size of the lateral offsets was approximately 150 ft. Due to runway maintenance, the left 150 feet of 300 foot wide Runway 22 at Edwards AFB was closed during the test period. The centerline of the remaining 150 foot wide runway was used for touchdown. The aircraft was flown on the desired glidepath using ILS until the beginning of the overrun, then the correction to the desired touchdown point was initiated. The safety pilot assisted in maintaining a constant correction and break point among the three project pilots.

The touchdown zone was 1000 feet long starting at 500 feet from the threshold and extending to 1500 feet from the threshold. The desired touchdown aim point was 1000 feet from the threshold and within 5 feet of centerline. Even though the ILS glide path intersected the runway at the desired touchdown point, the pilots were still required to make a large longitudinal correction (push over) due to the long flare characteristics of the NT-33A. Each landing was treated as a "must land" situation, unless the instructor/safety pilot or project pilot determined that safety of flight would be compromised in an attempt to land.

Table 6 summarizes the evaluation task performance criteria used to assign Cooper-Harper ratings to the visual landing task.

Table 6: Task Performance Criteria

Desired	**Adequate**
No PIOs Touchdown within 5 ft of centerline (main wheels on centerline) Touchdown aim point +/- 250 feet Approach airspeed +/-5 kts	Touchdown within 25 ft of centerline (tip tank on centerline) Touchdown at aimpoint +/- 500 feet Approach airspeed +/- 10 kts

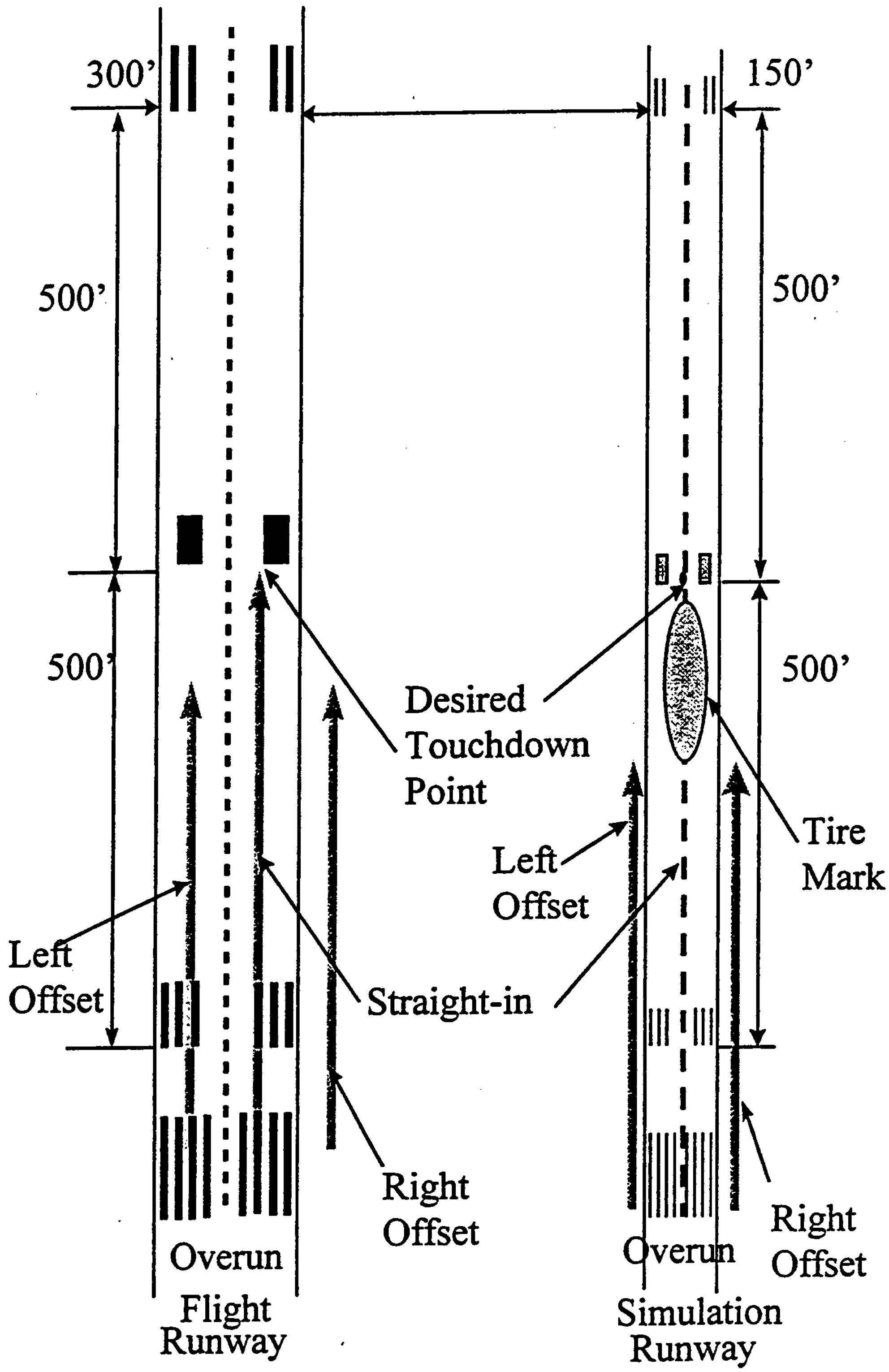


Fig. 1 Runway Configuration in Flight and in Phase I Ground-Based Simulation
(approximate to scale)

2.4 Cooper-Harper and Pilot-Induced Oscillation Rating Scales

The Cooper-Harper Rating (CHR) and the PIO Rating (PIOR) scales of Reference [8] were used in the HAVE PIO flight test. Figure 2 shows the Cooper-Harper scale. Figure 3 is the first PIO rating scale. It shows a flow chart of PIO ratings where the pilot arrives at a rating by answering series of questions. The second PIO scale in Table 7 is similar to the first but uses definitions to arrive at numerical ratings. It was primarily used to help pilots distinguish between "oscillations" and "bobbles". During practice runs of the simulation evaluation, pilots occasionally jumped to PIO ratings of 4 when they saw small oscillations that were more like bobbles than PIOs. These PIO ratings were given even though CHRs and pilot comments indicated desired performance and low PIO tendencies. The key phrase to help pilots distinguish between the bobbles and oscillations was "pilot must reduce gain or abandon task to recover."

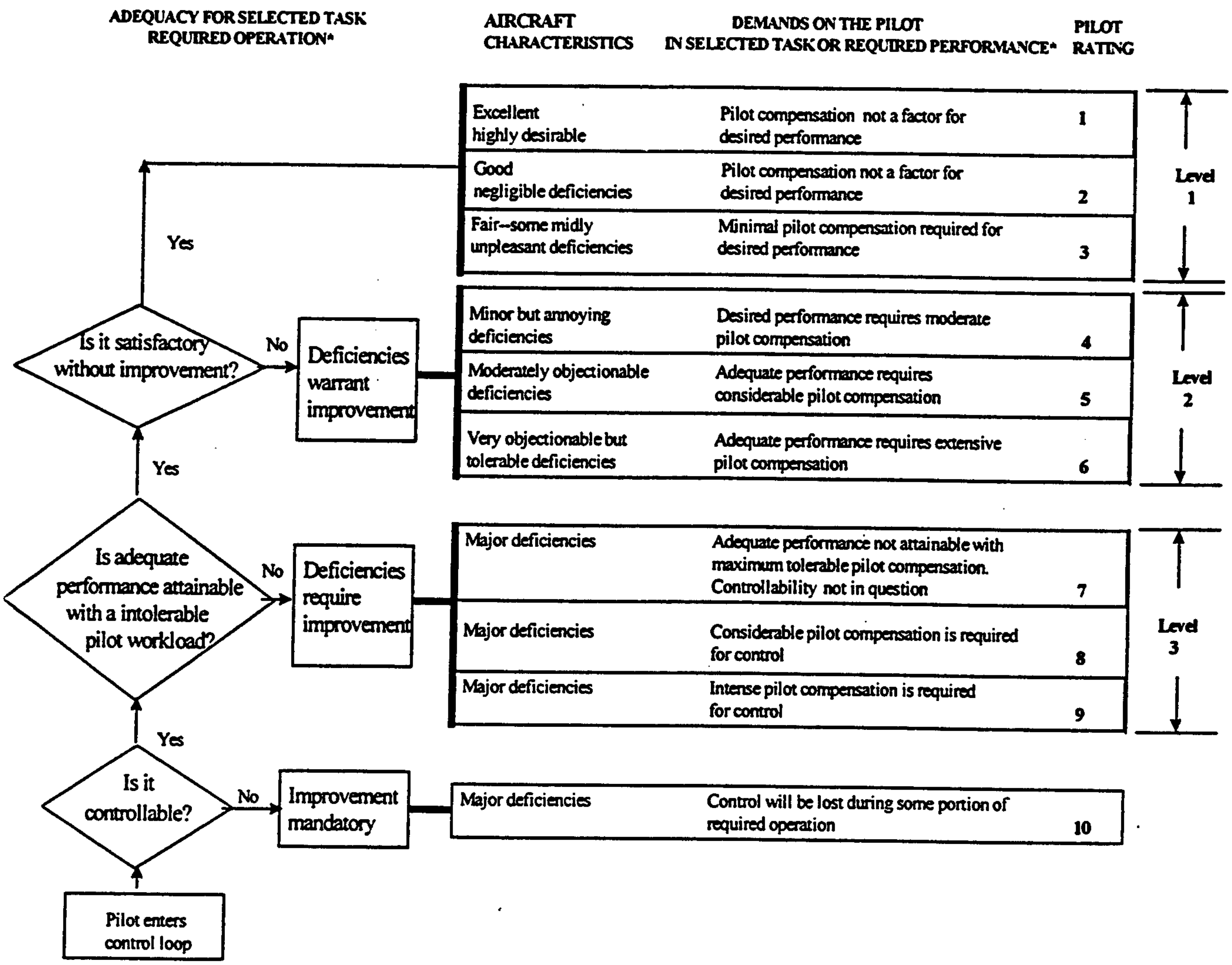


Fig. 2 Cooper-Harper Rating Scale

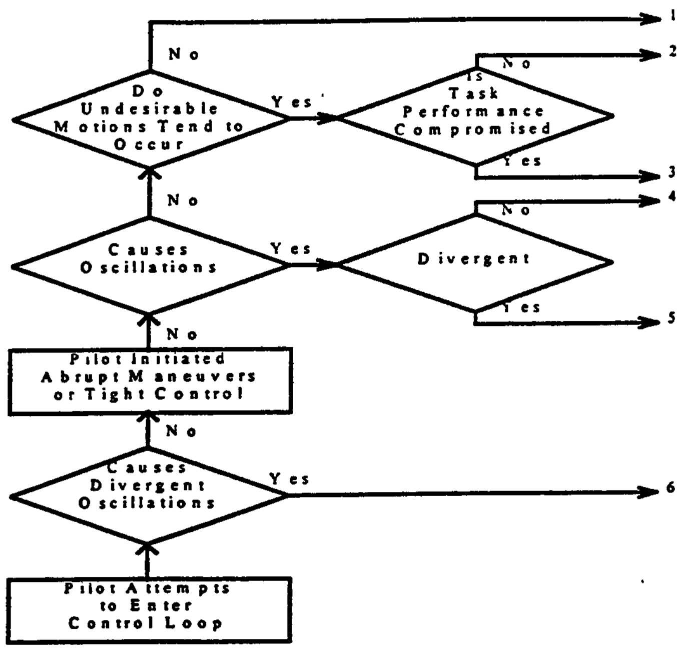


Fig. 3 PIO Tendency Rating Scale

Table 7: Description of Numerical PIORs

Description	#
No tendency for pilot to induce undesirable motions.	1
Undesirable motions tend to occur when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique.	2
Undesirable motions easily induced when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated but only at sacrifice to task performance or through considerable pilot attention and effort.	3
Oscillations tend to develop when pilot initiates abrupt maneuvers or attempts a tight control. Pilot must reduce gain or abandon task to recover.	4
Divergent oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must open loop by releasing or freezing the stick.	5
Disturbance or normal pilot control may cause divergent oscillation. Pilot must open control loop by releasing or freezing the stick.	6

2.5 Flight Test Pilot Comment Cards

Appendix A contains a sample of the flight test pilot comment cards. The cards include all summarized comments, PIO and Cooper-Harper ratings, information of the filters used and the values of K_θ selected . The filter information in the pilot comment cards represented the filters in the model development and was summarized in the following form.

$$(a) = (s + a)$$
$$[\xi, \omega_n] = (s^2 + 2\zeta\omega_n s + \omega_n^2)$$

2.6 Flight Test Results

Eighteen configurations were flown by at least two out of three project pilots. PIO and Cooper-Harper ratings, time histories, and pilot comments were collected for data analysis. All data were documented in [6,7]. Representative time history plots of F_s, θ , q, and a_{zp} for the last 30 seconds of the approach and landing for each configuration are shown in Appendix A. Recently, the digital data from the flight program was acquired from Calspan for time history analysis comparison. The time history analysis used a pilot stick input and a pitch rate response of the airplane for both flight and simulation data. The PIO characteristics (frequency, magnitude and phase lag) of flight data were compared to the simulation for correlation. A complete time history analysis of the program will be in a final report.

There are some questions about the ground rules which the engineers used to brief the pilots for CH and PIO ratings in flight. Did the pilots give a 10 in CHR and a 6 in PIOR when the safety pilot took over the control of the aircraft or when the evaluation pilot abandoned the task? Did they give these ratings when one approach failed in three attempts? Here are some of these examples which showed some inconsistencies in the pilots' ratings.

For configuration 2-5, pilot B gave CHR of 7 and PIOR of 4, due to PIO that caused the approach to be abandoned in first attempt, and poor performance in later runs. This may be inconsistent with some of the later ratings in that it did get a CHR of 10. Is this a subtle difference between task abandonment and safety pilot take over?

For configuration 2-5, pilot A had a desired performance except for "dropped in" sink rate, but he gave CHR of 10.

For configuration 2-7, pilot C got only adequate touchdown performance, and medium sink rate, but he gave CHR of 4.

For configuration 3-1, pilot C got only adequate touchdown performance, and medium sink rate, but he gave CHR of 4.

For configuration 3-3, pilot C had a long touchdown, but he gave CHR of 3.

For configuration 3-6, pilot C had a long touchdown, but he gave CHR of 4.

For configuration 4-1, pilot C had a long touchdown, and medium sink rate, but he gave CHR of 3.

For configuration 4-1, pilot A had a long touchdown due to winds at 50 deg., 6 kts gusting to 14 kts, but he gave CHR of 3.

For configuration 5-9, pilot A abandoned approach at least once due to PIO, but he gave CHR of 7.

For configuration 5-9, pilot B abandoned an approach at least once due to PIO, but he gave CHR of 8.

For configuration 5-11, pilot B missed two approaches, but he gave CHR of 7.

Table 8 shows the configurations, the pilot, the abandoned approaches, the pilot CHR along with the winds and gusts.

Table 8: Configurations, Pilots, Abandoned Approaches, Pilot CHRs and Winds/Gusts

Config.	Pilot	Abandoned approaches	CHR	winds
2-B	A	0	7	
2-B	B	0	3	
2-B	C	0	3	
2-B	C	0	3	
2-1	A	0	2	
2-1	B	0	2	70 deg @ 15kts
2-1	C	0	2	
2-5	A	0	10	
2-5	B	1	7	210 deg @ 8-10kts
2-5	C	3	10	
2-7	A	0	7	
2-7	B	0	4	210 deg @ 8-10kts
2-7	C	0	4	
2-8	A	2	8	
2-8	B	3	10	
2-8	C	3	8	
3-D	A	0	2	
3-D	C	0	2	
3-1	A	0	5	
3-1	B	0	3	
3-1	C	0	4	
3-3	A	S	7	

Table 8: Configurations, pilots, abandoned approaches, Pilot CHRs and winds/gusts (cont.)

Config.	Pilot	Abandoned approaches	CHR	Winds
3-3	B	0	2	
3-3	C	0	3	
3-6	A	0	5	50 deg. @ 15kts
3-6	C	0	4	
3-8	A	S	8	
3-8	B	0	5	
3-8	C	3	8	
3-12	B	0	7	
3-12	C	3	9	
3-13	A	3	10	60 deg @ 10 to 18 kts
3-13	C	3	10	
4-1	A	0	3	50 deg @ 6 to 14 kts
4-1	B	0	2	210 deg @ 10 to 18
4-1	C	0	3	
4-2	A	0	3	
4-2	B	0	3	
4-2	C	0	4	
5-1	A	0	2	
5-1	C	0	5	
5-9	A	S	7	
5-9	B	S	8	headwind at 10 kts
5-9	C	S	7	
5-10	A	3	10	
5-10	C	3	10	
5-11	A	0	7	
5-11	B	2	7	
5-11	C	0	5	

* Note: "S" in the abandoned approaches column means the safety pilot took over controls of the aircraft.

Table 9 summarizes the PIO and Cooper-Harper ratings for each configuration.

Table 9: HAVE PIO PIO and Cooper-Harper Ratings

Conf.	Pilots	PIO Ratings	Cooper-Harper Ratings	Winds
2-B	A/B/C/C	3 / 2 / 2 / 1	7 / 3 / 3 / 3	/headwind @ 20 to 18 kts
2-1	A/C/B	1 / 1 / 1	2 / 2 / 2	/70 deg @ 15 kts
2-5	A/B/C	4 / 4 / 5	10 / 7 / 10	/210 deg @ 10 to 18 kts
2-7	A/B/C	4 / 3 / 2	7 / 4 / 4	/210 deg @ 10 to 18 kts
2-8	A/B/C	4 / 4 / 4	8 / 10 / 8	
3-D	A/ C	1 / 1	2 / 2	
3-1	A/B/C	3 / 2 / 2	5 / 3 / 4	
3-3	A/B/C	3 / 1 / 1	7 / 2 / 3	
3-6	A/ C	2 / 2	5 / 4	50 deg @ 15 kts
3-8	A/B/C	4 / 3 / 4	8 / 5 / 8	
3-12	B/C	4 / 5	7 / 9	
3-13	A/ C	4 / 5	10 / 10	/60 deg @ 10 to 18 kts
4-1	A/B/C	1 / 1 / 1	3 / 2 / 3	50 deg @ 6 to 14 kts /210 deg @ 10 to 18 kts
4-2	A/B/C	1 / 1 / 2	3 / 3 / 7	
5-1	A/B/C	1 / 1	2 / 5	
5-9	A/ C	4 / 4	7 / 7	/headwind @10 kts
5-10	A/ C	5 / 5	10 / 10	
5-11	A/B/C	2 / 4 / 3	7 / 7 / 5	/30 deg @15 kts

3. GROUND SIMULATION MODEL DEVELOPMENT

The purpose of ground simulation was to duplicate and to predict what happened in flight as close as possible. It was hoped that minimizing differences between the two environments (ground simulation and flight) would make the results closer. Non-real-time and real-time ground simulations were developed. The real-time simulation model implemented the non-real-time simulation model in LAMARS and MS-1.

3.1 Non-Real-Time Simulation Model Development

Fixed stability derivatives in transfer function form of the HAVE PIO flight test model were used as the aircraft model for the non-real-time simulation model. The aircraft equations of motion, flight control systems and aircraft actuators were implemented in MATLAB. Since the flight test checkcases were taken from the input after the feel system to the aircraft output, the non-real-time simulation was modeled without the feel system. Three steps of the non-real-time simulation model development process are: stability derivative calculations, equations of motion, and model validation.

3.1.1 Stability Derivative Calculations

The longitudinal and some lateral stability derivatives were given in References [6,7]. However, some lateral stability derivatives, which were not given in References [6,7], can be developed from the following equations in Reference [11].

$$\frac{\varphi}{\delta_a} = \frac{N^{\varphi}_{\delta a}}{\Delta\ lat} \quad ; \quad \frac{r}{\delta r} = \frac{N^{r}_{\delta r}}{\Delta\ lat} \quad ; \quad \text{etc.}$$

The denominator, $\Delta\ \text{lat} = A_{lat}s^4 + B_{lat}s^3 + C_{lat}s^2 + D_{lat}s + E_{lat}$ (1)

The numerators; $N^{\varphi}_{\delta} = A_{\phi}s^2 + B_{\phi}s^2 + C_{\phi}$

$$N^{r}_{\delta} = A_r s^3 + B_r s^2 + C_r s + E_r$$
$$N^{p}_{\delta} = A_p s^3 + B_p s^2 + C_p s + E_p$$
$$N^{\beta}_{\delta} = A_{\beta} s^3 + B_{\beta} s^2 + C_{\beta} s + E_{\beta}$$

where

$$A_{\phi} = A_p + A_r \tan\theta_0$$
$$B_{\phi} = B_p + B_r \tan\theta_0$$
$$C_{\phi} = C_p + C_r \tan\theta_0$$

The values of A_p, A_r, B_p, B_r and A_{lat}, B_{lat}, C_{lat}, D_{lat} E_{lat} in terms of the stability derivatives are in Reference [11]. The transfer function; $\frac{\phi}{\delta_a}$ can be expressed in a de-coupled form.

$$\frac{\varphi}{\delta_a} = K_\phi \frac{\left(s^2 + 2\varsigma_\phi \omega_\phi s + \omega_\phi^2\right)}{\left(s^2 + 2\varsigma_d \omega_d s + \omega_d^2\right)\left(s + \frac{1}{T_r}\right)\left(s + \frac{1}{T_s}\right)} \quad (2)$$

The following seven equations which were used to calculate the derivatives; Y_v, L'_β, L'_p, L'_r, $L'_{\delta a}$, N'_β, N'_r, $N'_{\delta a}$ are derived from equations (1) and (2) by setting their coefficients equally.

$$\omega_\phi^2 = \frac{L'_{\delta a} Y_v N'_r - N'_{\delta a} Y_v L'_r + \frac{U_0}{V_{To}}\left(L'_{\delta a} N'_\beta - N'_{\delta a} L'_\beta\right) + \left[N'_{\delta a} Y_v L'_p + \frac{Wo}{V_{To}}\left(L'_{\delta a} N'_\beta - N'_{\delta a} L'_\beta\right)\right] \tan\theta_0}{L'_{\delta a} + N'_{\delta a} \tan\theta_0} \quad (3)$$

$$2\zeta_0 \omega_\phi^2 = \frac{-L'_{\delta a} N'_r - L'_{\delta a} Y_v + N'_{\delta a} L'_r + \left(L'_{\delta a} N_p - N'_{\delta a} Y_v - N'_{\delta a} L'_p\right) \tan\theta_0}{L'_{\delta a} + N'_{\delta a} \tan\theta_0} \quad (4)$$

$$2\varsigma_d \omega_d + \frac{1}{T_r} + \frac{1}{T_s} = -Y_v - L_p - N'_r \quad (5)$$

$$\omega_d^2 + \frac{2\varsigma_d \omega_d}{T_r} + \frac{2\varsigma_d \omega_d}{T_s} + \frac{1}{T_r T_s} = \frac{U_0}{V_{To}} N'_\beta + L'_p Y_v + L'_p N'_r + Y_v N'_r - \frac{W_0}{V_{To}} L'_p \quad (6)$$

$$\frac{\omega_d^2}{T_r} + \frac{\omega_d^2}{T_s} + \frac{2\varsigma_d \omega_d}{T_r T_s} = -\frac{U_0}{V_{To}} L'_p N'_\beta - Y_v L'_p N'_r - \frac{g}{V_{To}}\left(L'_\beta \cos\theta_0 + N'_\beta \sin\theta_0\right) + \frac{W_0}{V_{T0}}\left(L'_\beta N'_r - N'_\beta L'_r\right) \quad (7)$$

$$\frac{\omega_d^2}{T_r T_s} = \frac{g}{V_{To}}\left(L'_\beta N'_r \cos\theta_0 - N'_\beta L'_r \cos\theta_0 - L'_p N'_\beta \sin\theta_o\right) \quad (8)$$

$$\left|\frac{\phi}{\beta}\right|_d^2 = \frac{L'^2_\beta + \omega_d^2 L'^2_r + 2\varsigma_d \omega_d L'_r L'_\beta}{\omega_d^2 + \omega_d^2 L'^2_p + 2\varsigma_d \omega_d^2 L'_p} \quad (9)$$

For the landing task, the value of $Y^*_{\delta a}$ is negligible. The above seven equations were optimized in MATLAB with the following given initial conditions: $L'_{\delta a} = 7$, $N_p' = 0.1$, $g=32.2$, $\theta_0 = 4.5$ degrees, $U_0 = 205$, $W_0 = 25$, $W_p = 1.3$, $Z_p = 0.2$, $W_d = 1.3$, $Z_d = 0.2$, $T_r = 0.3$, $T_s = 75$ and $\left|\frac{\phi}{\beta}\right|_d^2 = 1.5$. The values of the lateral derivatives are in Table10.

Table 10: Values of Lateral Derivatives

Y_v	-0.2234
L'_β	-6.7492
L'_p	-3.4125
L'_r	0.6701
N'_β	1.0873
N'_r	-0.2308
$N'_{\delta a}$	0.3228
N'_p	-0.1000
$L'_{\delta a}$	4.0110

3.1.2 Equations of Motion

The following equations of motion, filters, and the actuators were implemented in MATLAB for the non-real time simulation. These equations were from Reference [12].

3.1.2.1 Translational Equations

$$\dot{U} = rv - qW + g\sin\theta_0 + 2g(e_2e_4 - e_1e_3) + X_u u + X_w w + X_{\delta e}\delta_e$$

$$\dot{V} = pW - rU + 2g(e_3e_4 + e_1e_2) + Y_v v + V_{T0}Y^{*}_{\delta a}\delta_a + V_{T0}Y^{*}_{\delta r}\delta_r$$

$$\dot{W} = qU - pv - g\cos\theta_0 + g(e_1^2 + e_4^2 - e_2^2 - e_3^2) + Z_u u + Z_{\dot{w}}\dot{w} + Z_w w + Z_{\delta e}\delta_e$$

3.1.2.2 Rotational Equations

$$\dot{P} = \frac{pqI_{xz}(I_{yy} - I_{xx} - I_{zz}) + qr\left(I_{xz}^2 + I_{zz}^2 - I_{zz}I_{yy}\right)}{\left(I_{xz}^2 - I_{xx}I_{zz}\right)} + L'_\beta\frac{v}{V_{T0}} + L'_p p + L'_r r + L'_{\delta a}\delta_a + L'_{\delta r}\delta_r$$

$$\dot{Q} = \frac{pr\left(I_{zz} - I_{xx}\right) + r^2 I_{xz} - p^2 I_{xz}}{I_{yy}} + M_u u + M_{\dot{w}}\dot{w} + M_w w + M_q q + M_{\delta e}\delta_e$$

$$\dot{R} = \frac{pq\left[I_{xx}\left(I_{yy} - I_{xx}\right) - I_{xz}^2\right] + qrI_{xz}\left(I_{zz} - I_{yy} - I_{xx}\right)}{\left(I_{xz}^2 - I_{xx}I_{zz}\right)} + N'_\beta\frac{v}{V_{To}} + N'_p p + N'_r r + N'_{\delta a}\delta_a + N'_{\delta r}\delta_r$$

3.1.2.3 Position Equations

$$\dot{X} = U(e_1^2 + e_2^2 - e_3^2 - e_4^2) + V[2(e_2e_3 - e_1e_4)] + W[2(e_2e_4 + e_1e_3)]$$

$$\dot{Y} = U[2(e_2e_3 + e_1e_4)] + V(e_1^2 - e_2^2 + e_3^2 - e_4^2) + W[2(e_3e_4 - e_1e_2)]$$

$$\dot{H} = -U[2(e_2e_4 - e_1e_3)] - V[2(e_3e_4 + e_1e_2)] + W(e_1^2 - e_2^2 - e_3^2 + e_4^2)$$

3.1.2.4 Quaternion Equations

$$\dot{e}_1 = \frac{1}{2}\left(-e_2\mathrm{P} - e_3Q - e_4R\right)$$

$$\dot{e}_2 = \frac{1}{2}\left(e_1\mathrm{P} + e_3R - e_4Q\right)$$

$$\dot{e}_3 = \frac{1}{2}\left(e_1Q - e_2R + e_4P\right)$$

$$\dot{e}_4 = \frac{1}{2}\left(e_1R + e_2Q - e_3P\right)$$

3.1.2.5 Kinematics Equations

$$\theta = \sin^{-1}\left[-2\left(e_2e_4 - e_1e_3\right)\right]$$

$$\phi = \tan^{-1}\left[\frac{2\left(e_3e_4 + e_1e_2\right)}{\left(e_1^2 - e_2^2 - e_3^2 + e_4^2\right)}\right]$$

$$\psi = \tan^{-1}\left[\frac{2\left(e_2e_3 + e_1e_4\right)}{\left(e_1^2 + e_2^2 - e_3^2 - e_4^2\right)}\right]$$

3.1.2.6 Flight Control Systems Equations

$$\ddddot{\delta}_{es'} = -\left(2\varsigma_{n2}\omega_{n2} + 2\varsigma_{n1}\omega_{n1}\right)\dddot{\delta}_{es} - \left(4\varsigma_{n1}\omega_{n1}\varsigma_{n2}\omega_{n2} + \omega_{n1}^2 + \omega_{n2}^2\right)\ddot{\delta}_{es}$$
$$-\left(2\omega_{n2}^2\omega_{n1} + 2\omega_{n1}^2\varsigma_{n2}\omega_{n2}\right)\dot{\delta}_{es} - \omega_{n1}^2\omega_{n2}^2\delta_c + \mathrm{K}\delta_{ec}$$

$$\dddot{\delta}_{es'} = \mathrm{K}_4\dddot{\delta}_{es}$$

$$\ddot{\delta}_{es'} = \mathrm{K}_2\left(-2\varsigma_{n1}\omega_{n1}\delta_{es} - \omega_{n1}^2\dot{\delta}_{es} + \mathrm{K}\delta_{ec}\right) + \mathrm{K}_4\ddot{\delta}_{es}$$

$$\dot{\delta}_{es'} = K_1(-\tau\delta_{es} + K_2\delta_{ec}) + K_2\dot{\delta}_{es} + K_4\dot{\delta}_{es}$$

Some extra states were required when a first-order flight control system used. The following states are:

$$\dot{\delta} = \mathrm{K}\left(\tau_1 - \tau_2\right)\delta_{es} - \tau_2\delta$$

$$\delta_e = k\delta_{es} + \delta_e$$

3.1.2.7 Actuator Equations

$$\ddot{\delta}_e = -2\varsigma_a\omega_a\dot{\delta}_e - \omega_a^2\delta_e + \omega_a^2\delta_{es}$$

$$\ddot{\delta}_a = -2\varsigma_a\omega_a\dot{\delta}_a - \omega_a^2\delta_a + \omega_a^2\delta_{ac}$$

$$\ddot{\delta}_r = -2\varsigma_a\omega_a\dot{\delta}_r - \omega_a^2\delta_r + \omega_a^2\delta_{rp}$$

The appropriate flight control values for the 18 configurations in References [6,7] are in Table 11. The first column is the configuration. The second through the fifth column shows the constant values of the flight control system for each configuration. The sixth through the eleventh column shows the damping, frequencies and the time constant of the flight control systems.

Table 11: Values of Flight Control System of 18 Configurations

Config.	K	K_1	K_2	K_4	ζ_1	ω_1	ζ_2	ω_2	τ_1	τ_2
2-B	3	1	0	0	---	---	---	---	3.33	10
2-1	1	1	0	0	---	---	---	---	---	---
2-5	1	1	0	0	---	---	---	---	---	1.0
2-7	144	0	1	0	0.7	12	---	---	---	---
2-8	81	0	1	0	0.7	9	---	---	---	---
3-D	0.5	1	0	0	---	---	---	---	20	10
3-1	1	1	0	0	---	---	---	---	---	---
3-3	4	0	1	0	---	---	---	---	---	4.0
3-6	256	0	1	0	0.7	16	---	---	---	---
3-8	81	0	1	0	0.7	9	---	---	---	---
3-12	4	0	1	0	0.7	2	---	---	---	---
3-13	9	0	1	0	0.7	3	---	---	---	---
4-1	1	1	0	0	---	---	---	---	---	---
4-2	10	1	0	0	---	---	---	---	---	10
5-1	1	1	0	0	---	---	---	---	---	---
5-9	36	0	1	0	0.7	6	---	---	---	---
5-10	16	0	1	0	0.7	4	---	---	---	---
5-11	65536	0	0	1	0.93	16	0.38	16	---	---

In References [6,7], the damping and frequency values of the actuator used in the simulation were at 0.7 and 75 Hz. The values of moments of inertia used in the simulation were: I_{xx} = 15000, I_{yy}= 20000, I_{zz} = 35000, I_{xz} = 500. In the non-real-time simulation, the feel system characteristics were not modeled. However, they were modeled as in Reference [6,7] for the real-time simulation.

3.1.3 Non-Real -Time Simulation Model Validation

Prior to a data collection in flight, the HAVE PIO model was verified and validated with a computer-generated step input. A hard copy of the pitch rate response was also collected at the time for the model verification. The pitch rate time history plots of the non-real time MATLAB model and flight were visually matched well. These checkcases of the 18 configurations are shown in Appendix C.

3.2 Real -Time Simulation Model Development

The non-real-time simulation model in Section 4.1 along with the flight feel system were implemented in LAMARS and MS-1 for a real-time simulation. During flight test, the "gearing" ratio (it was also called K_θ) between the elevator and the stick position was selected for each configuration by the first pilot to fly it; on subsequent evaluations the gearing remained set at the value initially selected. In the simulators, the "gearing" ratio was not set to the same values as in flight but was also set for all configurations by the first pilot to fly a given configuration. A lesson learned here is to validate the ground simulation against the flight test model, the stick gains must be included into a simulation validation process. This is important. Most of the time, engineers tended not to include the stick gains in the simulation validation because flight check-cases did not include the stick gains. In most cases, the stick gains will be set during a dry run of the simulation. The simulation engineers normally would ask a dry run pilot to set the stick gains and then would leave it alone for the rest of the evaluation.

3.3 Real -Time Simulation Validation

In addition to matching the time history of the non-real-time simulation, a dry run of the real-time simulation with a "corruptible" pilot prior to pilot-in-the loop evaluation was required. During the dry run, the pilot flew the entire test matrix and gave feedback about the objectives and setup of the simulation overall. Only after assuring that the pilots could fly the tasks and give meaningful evaluations and that valid engineering data would be gathered, were the pilot-in-the-loop evaluations conducted.

3.4 Ground Simulation Runway Model

The runway of the real time simulation shown in Figure 1 was modeled as close as possible to that used in the flight experiment. The runway model was used in Phase I. In Phase II, several modifications were added to the runway configuration in order to increase the pilot's gain. The shaded circle just below the touchdown point was the tire mark region, which helped the pilots to estimate where they touched down in relation to the desired touchdown point.

3.5 Safety Pilot and Automatic Trips

In-flight, the safety pilot would take controls over whenever he felt the evaluation pilot in a danger. The automatic safety trips cause the system to revert to the baseline aircraft whenever

the evaluation pilots operated outside the simulation boundary. The safety pilot and automatic trips were not implemented in ground simulation.

4. GROUND SIMULATION TEST SET-UP

4.1 Pilots

The evaluation pilots of HAVE PIO program in both Phase I and II were Air Force Test Pilot School (TPS) graduates. They are all familiar with CHR and PIOR. With an exception of one pilot, each pilot had more than 2000 hours of flying time. These pilots stationed at Wright Patterson AFB. Their experiences included bomber, attack, and fighter aircraft training. The mixed flying experiences among the pilots were helpful in evaluating PIO problems. Due to the pilots' schedule, some pilots did not participate in both phases of the program. Table 12 shows the pilot flying time by aircraft of all pilots who participated in the program.

Table 12: Pilots' Flying Time

	A	B	C	D	E	F	G	H	I
F-15	800	-	-	700	-	1100	400	1500	-
F-16	500	2100	-	1200	1200	-	-	-	1017
F-18	350	-	-	-	-	-	-	-	-
F-111	-	-	-	-	-	-	1100	-	-
F-4	-	-	-	-	-	-	-	230	-
A-10	-	-	-	-	1000		-	-	-
A-7	-	250	-	-	600	-	200	-	-
B-52	-	-	1100	-	-	-	-	-	1756
B-2	-	-	-	-	-	-	-	-	126
T-38	800	200	1800	100	100	1100	150	-	
T-39	-	-	-	-	-	-	-	-	-
O-2	-	-	-	-	300	-	-	-	-
OV-10	-	-	-	700	250	-	-	-	-
C-130	-	-	-	-	-	-	-	180	-
C-23	-	-	-	-	-	-	-	230	-

4.2 Pilot Pre-briefing and Debriefing

Pilots normally came to the pre-briefing about half an hour prior to their evaluations. The engineers briefed the pilots about the simulation plan in detail. The plan included the performance criteria, the aircraft configurations, the tasks, the runway configuration, and Cooper-Harper and PIO rating scales. After a completion of their simulation sessions, the pilots debriefed the engineers about their evaluations.

4.3 Pilot Familiarization

Each evaluation pilot had approximately half of an hour for simulation familiarization. The purpose of this was to let the pilot get familiar with the cockpit, and to experience the

dynamics of the configurations. Pilots flew three configurations of the test matrix. These configurations had different dynamics and ranged from good, to bad, to ugly in handling qualities. During the familiarization landings, the engineers fed back to the pilots the touchdown position along with the sink rate and the touch down speed. This was very helpful to the pilots to calibrate where they landed in relation to the desired touchdown point. This information was not given back to the pilots during the actual evaluations.

4.4 Evaluation Task

The landing task used in the HAVE PIO flight program [6,7] was duplicated in the simulator. Pilots used the long look technique of Reference [10] for their evaluation. Each landing was treated as a "must land" situation and was flown a minimum of three times before giving PIO and Cooper-Harper ratings. Three landings consisted of a straight-in, followed by left and right offset approaches. Turbulence, winds, and gusts were not modeled in Phase I, but they were in Phase II. The ground effects were modeled based on the information in Reference [13]. For using the PIO Rating Scale, **PIO is defined as in flight test.**

4.4.1 Landing Task Success Criteria

In flight the pilots were to assess the touchdown sink rates as high, medium or low. This assessment was to be included in the pilot commentary and was not to directly influence the pilot rating in ground simulation. Pilots have historically had difficulty in determining the sink rates in simulators due to degraded visual cues and the lack of a complete motion cues set. As a way to account for this, the pilots were given the sink rates during their familiarization runs to help them to get calibrated to the simulation environment. The sink rates were then added to the desired and adequate criteria in an attempt to increase pilot awareness of the task in both Phase I and II ground simulation.

4.4.1.1 Desired Performance Criteria

The simulation used the same criteria as in flight. These criteria were: 1) pilots must land the aircraft within 5 feet of the runway centerline, at +/- 250 feet from the desired touchdown point in longitudinal direction. 2) no PIOs and 3) approach airspeed were at +/- 5 knots. Additionally, for the simulation, touchdown sink rate was to be less than or equal to 4 feet per second.

4.4.1.2 Adequate Performance Criteria

The simulation used the same criteria as in flight. These criteria were: 1) pilots must land the aircraft within 25 feet of the runway centerline, and at +/- 500 feet from the desired touchdown point in longitudinal direction, 2) approach airspeed were at +10/-5 knots. In addition, touchdown sink rate was to be less than or equal to 8 feet per second.

4.4.2 Straight-in Landing

The aircraft was trimmed at a 2.5 degree glideslope at 135 kts TAS, 300 feet AGL. Pilots flew the aircraft and landed on the desired touchdown point on the runway.

4.4.3 Offset Landing

The aircraft was trimmed at a 2.5 degree glideslope at 135 kts TAS, 300 feet AGL. The offsets were 150 ft from the runway centerline. Pilots maintained glide slope and heading while flying offset until they reached an altitude of 150 ft AGL. At that point, the break "X" in the HUD also disappeared, the pilots must correct to the runway centerline and attempt to land at the desired touchdown point on the runway.

4.5 Data Collection

Pilot comments, CHR and PIO ratings, the performance data and time history in digital format were collected during ground simulation along with audio and video data

5. PHASE I SIMULATION EVALUATION

5.1 Piloted Evaluation

The Phase I evaluation was conducted in LAMARS with and without motion and in MS-1 over a period of several months. The space between each evaluation was good for the engineers to look at the data before proceeding to the next evaluation. Five pilots flew MS-1. Four pilots flew LAMARS without motion. Three pilots flew LAMARS with motion. The four pilots who flew LAMARS without motion also flew MS-1. Two out of the three pilots who flew LAMARS with motion also flew MS-1. Phase I simulation data shown here represents the evaluation with the correct "gearing", and with a washed-out linear motion gain for LAMARS. Half a day of simulation time was scheduled for each evaluation. The remaining half day was used to prepare the simulation for the next day's evaluation. Engineers briefed the pilots prior to and after each simulation session. As mentioned earlier, the pilots flew each one of the 18 configurations depicted in Table 11 to the desired touchdown area on the runway. Pilot evaluations were begun with a straight-in approach and followed with left and right offset approaches. Pilots might request to repeat any of these approaches prior to giving ratings. Pilots generally knew the configuration which they were going to fly; however, they did not know the dynamics of the configuration prior to their evaluations. While flying a configuration, pilots were encouraged to comment about the dynamics of the configuration. This was helpful to the engineers for analyzing the data. After the completion of each configuration, pilots rated the configuration in Cooper-Harper and PIO rating scales.

5.2 Data Analysis

There were approximately 800 data points in Phase I collected from five test pilots and three simulators. The data obtained in Phase I are the Cooper-Harper and the PIO ratings which were validated with pilot comments and against the performance criteria. Some selected pilot comment cards in ground-based simulation are in Appendix D. It was found that sometimes the pilot ratings did not agree with the performance criteria. However, when those runs were removed from the data, the changes had insignificant effects to the trends of data. Therefore, the author chose to use the raw data for the analysis. Both flight and simulation data in mean and median Cooper-Harper and PIO ratings were compared for trends and correlation. The data were also presented in a statistical form for the readers to form their own opinion. There was a scatter in the data due to pilots' variability.

5.2.1 MS-1

Table 13 shows individual PIO ratings and statistical information for MS-1 and the HAVE PIO flight test program. Pilot ratings by different pilots are separated by slashes, multiple ratings by the same pilot are separated by commas. The statistical data presented here is in terms of mean, median and standard deviation. In general, the standard deviations of simulation in PIO ratings are higher than in flight. The confidence interval and the standard deviations of the simulation data may be improved with more sample collections.

With the exception of configuration 3-8, configurations in which PIOs were seen in flight resulted in PIOs seen by at least one pilot on MS-1. If the evaluation was stopped after two pilots flying these configurations on MS-1, the above results would not be seen. This is a good example of how sample size and pilot variability can affect results. For configurations 2-B, 3-D and 3-6, at least one pilot saw an oscillation in ground simulation but pilots did not see any oscillations for the same configurations in flight.

Table 13: MS-1 and HAVE PIO PIOR Data

Conf.	PIOR flight	PIOR MS-1	Mean flight	Mean MS-1	Median flight	Median MS-1	Std dev flight	Std dev MS-1
2-B	3/2/2,1	2/2/4/4,4/2	2.00	2.80	2.00	2.00	0.58	1.10
2-1	1/1/1	1/1/2/1/2	1.00	1.40	1.00	1.00	0.00	0.55
2-5	4/4/5	4/4/4/4/5	4.33	4.20	4.00	4.00	0.58	0.45
2-7	4/3/2	2/1/3/1/4	3.00	2.20	3.00	2.00	1.00	1.30
2-8	4/4/4	4/1/4/1/2	4.00	2.40	4.00	2.00	0.00	1.52
3-D	1/-/1	2/1/3/2/4	1.00	2.40	1.00	2.00	0.00	1.14
3-1	3/2/2	1/2/2/1/2	2.33	1.60	2.00	2.00	0.58	0.55
3-3	3/1/1	1/1/1/1,1/2	1.67	1.20	1.00	1.00	1.15	0.45
3-6	2/-/2	4/2/2/2/4	2.00	2.80	2.00	2.00	0.00	1.10
3-8	4/3/4	2/2/2/2/2,1	3.67	2.00	4.00	2.00	0.58	0.00
3-12	-/4/5	4/1/2/4/1	4.50	2.40	4.50	2.00	0.71	1.52
3-13	4/-/5	4/2/5/3/2,4	4.50	3.60	4.50	4.00	0.71	1.14
4-1	1/1/1	1/1/2/1,1/2	1.00	1.40	1.00	1.00	0.00	0.55
4-2	1/1/2	1/1/1/1/3	1.33	1.40	1.00	1.00	0.58	0.89
5-1	1/-/1	3/1/1/1/2	1.00	1.60	1.00	1.00	0.00	0.89
5-9	4/5/4	4/2/4/4/5	4.33	3.80	4.0	4.00	0.58	1.10
5-10	5/-/5	4/4/4/4/4,4	5.00	4.00	5.00	4.00	0.00	0.00
5-11	2/4/3	4/2,1/2/2/5	3.00	3.00	3.00	2.00	1.00	1.41

In Fig. 4, the median PIO ratings for each configuration from MS-1 are plotted against PIO ratings for the same configurations from HAVE PIO. The horizontal axis of the plot is median MS-1 PIO ratings. The vertical axis of the plot is median HAVE PIO PIO ratings. The 45 degree solid line in the plot represents one-to-one correlation for flight and ground simulation data. For best correlation, both flight and simulation data should lie on this line. An arbitrary error band similar to that used in CHR data was created for the PIOR data. The band was formed by two dashed-lines which were placed a half rating from both sides of the 45 degree line. For a good correlation, the PIO ratings of the 18 configurations of the simulation and flight should fall within the band. In Fig 4, 10 of the 18 flight test configurations were matched very closely by the simulation. In general, the median simulation data shows the same trends as seen in flight. However, the simulation data did not match the flight results. The non-PIO configurations (PIO <= 2) in MS-1 were non-PIO configurations in flight. The mediocre configurations (2<PIOR<4) in MS-1 ranged in flight from very good to bad. The worst

configurations (PIOR>4) in MS-1 were the worst configurations in flight; however, they were not as bad in ground simulation as they were in flight. Configurations 3-12 and 3-13 rated PIO in flight (PIOR>4) were rated from "no PIO tendencies" to "undesirable motions" (PIOR = 2 or 3) in ground simulation. Configurations 3-8, 2-8, 5-11 and 2-7 rated "undesirable motions" to "oscillations" (PIO = 3 and 4) in flight, were rated "no PIO tendencies" (PIOR = 2) in ground simulation. The worst configuration (5-10) in flight (PIO = 5) was also worst configuration in ground simulation (PIO = 4) but it was not as bad in ground simulation as it was in flight.

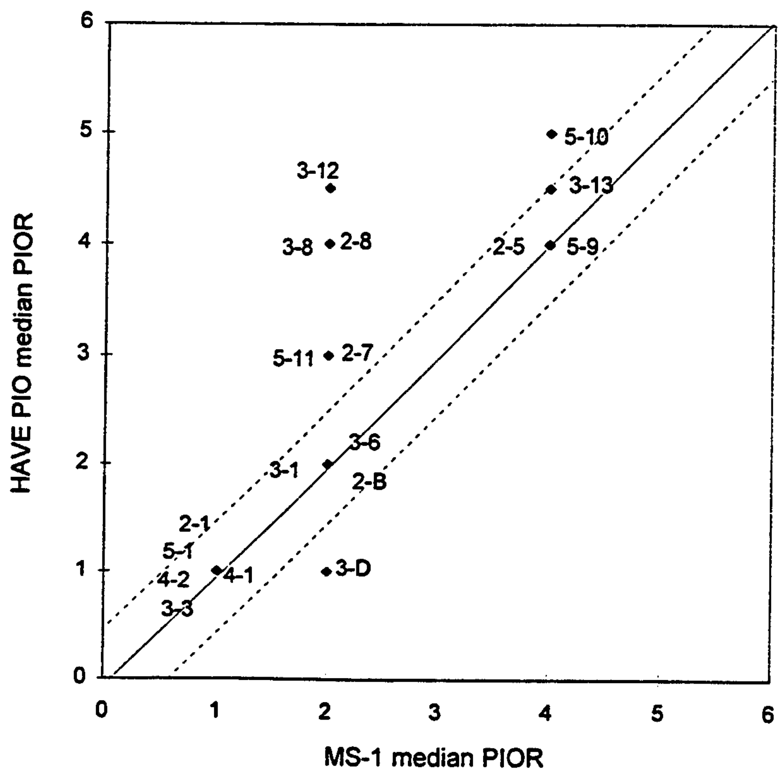


Fig. 4 MS-1 vs. HAVE PIO in Median PIOR

In Fig.5, mean PIO ratings for each configuration from MS-1 are plotted similarly. Seven of the 18 flight test configurations were matched by the simulation within the error band. Three out of these seven flight configurations (4-2, 5-11 and 2-5) were almost matched closely by the simulation. The configurations rated "no PIO tendencies" (PIOR = 1 and 2) in flight were also rated "no PIO tendencies" in ground simulation, with the exception of the configurations 3-D, 3-6, and 2-B. Configurations 3-D, 3-6, and 2-B that were rated "no PIO tendencies" in flight were rated "undesirable motion" in MS-1. These three configurations were rated as very sensitive configurations in the pitch responses on MS-1 by the pilots. The sensitivity which pilots sensed from the configurations on MS-1 could possibly come from the stick instead of the dynamics of the configuration. There were no complaints from the pilots about the sensitivity of these configurations in flight. Configurations (3-1, 3-8) rated "undesirable motion" to "oscillation" ($2<PIOR \leq 4$) in flight were rated "no PIO tendencies" to "undesirable motion" ($1<PIOR<2$) in

MS-1. Configurations (2-8 and 3-12) rated "oscillations" (PIOR $\geq$ 4) in flight were rated "undesirable motions" (2<PIOR<3) in MS-1. The worst configuration (5-10) rated "divergent oscillation" (PIOR = 5) in flight was rated "oscillation" in MS-1. In general, MS-1 mean PIO data shows the same trend as the median data.

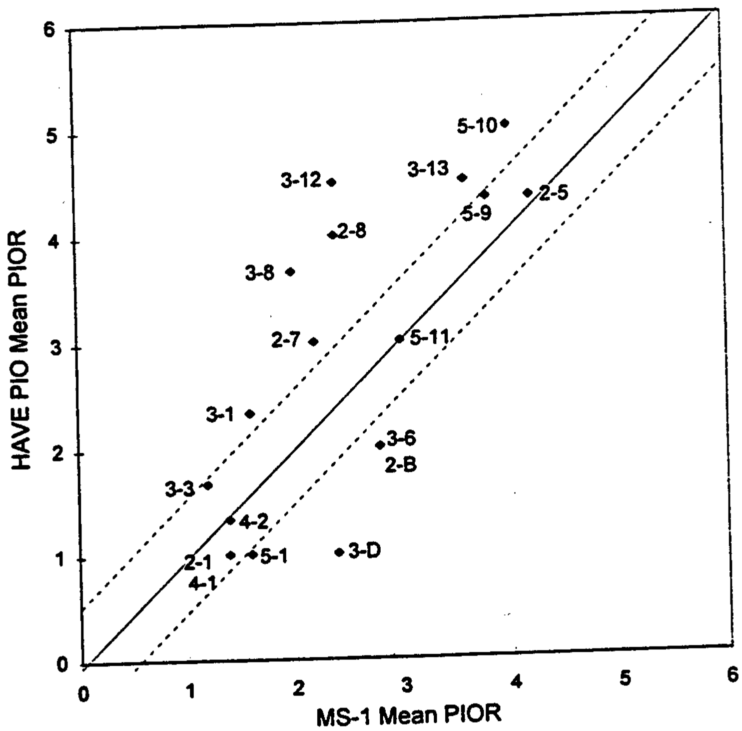


Fig. 5 MS-1 vs. HAVE PIO in Mean PIOR

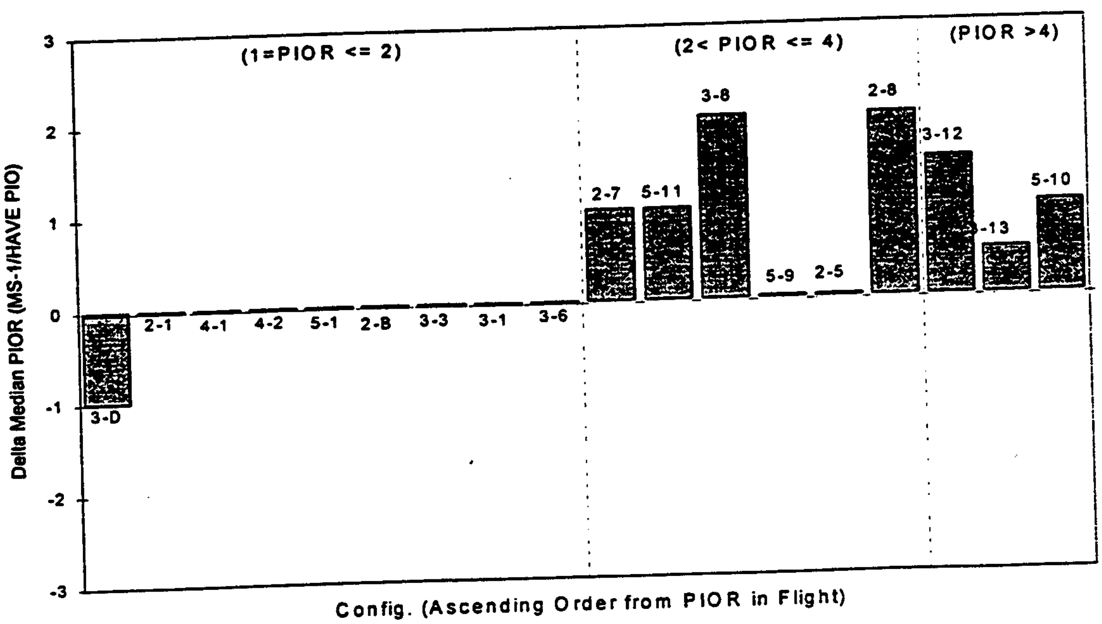


Fig. 6 MS-1/HAVE PIO in Median PIOR Differences

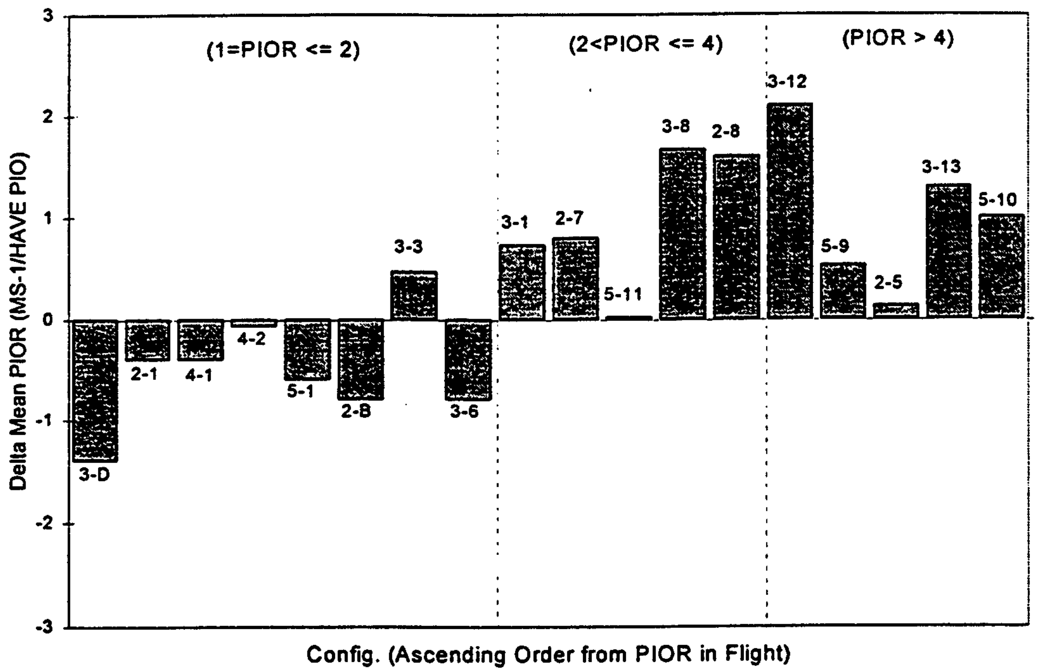


Fig. 7 MS-1/HAVE PIO in Mean PIOR Differences

Figures 6 and 7 show the difference (delta) in PIORs. A positive delta indicates higher ratings (greater PIO tendency) in flight than in the simulator. Configurations are ordered from best to worst based on median and mean PIOR from flight. The vertical dashed lines separate the data into regions roughly equivalent to flying qualities Levels.

Table 14 shows the individual Cooper-Harper ratings (CHRs) and statistical information for MS-1 and HAVE PIO. In Reference [14], standard deviations of less than or equal to 1.25 in CHR indicate reasonable data. In flight, 11 of the 18 configurations had standard deviations less than 1.25 and 12 of the 18 configurations for ground simulation. Three configurations in flight had standard deviations ≥ 2 which is why this flight data was questioned.

Table 14: MS-1 and HAVE PIO CHR Data

Conf.	CHR flight	CHR MS-1	Mean flight	Mean MS-1	Median flight	Median MS-1	Std dev flight	Std dev MS-1
2-B	7/3/3,3	4/3/6/5,4/4	4.00	4.40	3.00	4.00	2.00	1.14
2-1	2/2/3	3/1/4/1/3	2.33	2.40	2.00	3.00	0.58	1.34
2-5	10/7/10	6/7/7/7/7	9.00	6.80	10.0	7.00	1.73	0.45
2-7	7/4/4	4/4/5/2/5	5.00	4.00	4.00	4.00	1.73	1.22
2-8	8/10/8	5/3/6/5/4	8.67	4.60	8.00	5.00	1.15	1.14
3-D	2/2	4/2/5/3/5	2.00	3.80	2.00	4.00	0.00	1.30
3-1	5/3/4	2/3/4/2/3	4.00	2.80	4.00	3.00	1.00	0.84
3-3	7/2/3	2/3/1/3,4/3	4.00	2.60	3.00	3.00	2.65	1.14

Table 14: MS-1 and HAVE PIO CHR Data (cont.)

Conf.	CHR flight	CHR MS-1	Mean flight	Mean MS-1	Median flight	Median MS-1	Std dev flight	Std dev MS-1
3-6	5/4	5/3/3/3/5	4.50	3.80	4.50	3.00	0.71	1.10
3-8	8/5/8	4/4/4,3/3/3	7.00	3.60	8.00	4.00	1.73	0.55
3-12	7/9	6/4/4/6/4	8.00	4.80	8.00	4.00	1.41	1.10
3-13	10/10	6/5/8/6/5.4	10.0	6.00	10.0	6.00	0.00	1.22
4-1	3/2/3	2/2/5/2/2,1	2.67	2.60	3.00	2.00	0.58	1.34
4-2	3/3/4	2/1/1/1/5	3.33	2.00	3.00	1.00	0.58	1.73
5-1	2/5	4/1/2/3/4	3.50	2.80	3.50	3.00	2.12	1.30
5-9	7/8/7	6/3/7/7/6	7.33	5.80	7.00	6.00	0.58	1.64
5-10	10/10	6/5/7/6/6,5	10.0	6.00	10.0	6.00	0.00	0.71
5-11	7/7/5	5/2,3/4/5/6	6.33	4.60	7.00	5.00	1.15	1.14

In Fig. 8, the median CH ratings for each configuration from MS-1 are plotted against CH ratings for the same configurations from HAVE PIO. The horizontal axis of the plot is median MS-1 CH ratings. The vertical axis of the plot is median HAVE PIO CH ratings of HAVE PIO. The standard Cooper-Harper error band is formed by two dashed-lines which are placed at plus and minus one rating from the 45 degree line.

In general, the median data tended to be in two groups. The first group of data contained all good and some mediocre configurations. The CH ratings of these configurations were below 5 for both flight and ground. The second group of data contained all bad and some mediocre configurations. The CH ratings of these configurations were above 7 for flight and 5 for ground simulation. Configurations (2-1, 2-B, 3-D, 3-3, 4-1, 4-2 and 5-1) had good ratings (CHR ≤ 3.5) in flight and were also rated good in MS-1 (CHR ≤ 3.5) with the exception of the configuration 3-D. Three of the five pilots commented that configuration 3-D was sensitive in MS-1 and because of that all three pilots gave a high CH rating. There were no complaints from the pilots about the sensitivity of this configuration in flight. Configurations (5-9, 5-10, 5-11, 3-12, 3-8, 3-13 and 2-5) had bad CHR (6.5<CHR ≤10) in flight and were rated mediocre CHR (4 ≤ CHR ≤ 7) in MS-1. This was off by 3 CHRs which is equivalent to an entire Flying Qualities Level [8]. The configurations (3-6, 3-1 and 2-7), rated mediocre (3.5 <CHR<6.5) in flight, were rated the same or slightly better in MS-1. In general, the median data shows good configurations (CHR ≤ 3.5) in MS-1 will be good configurations in flight except configurations 3-1 and 3-6. The mediocre configurations in MS-1 (3.5 ≤ CHR ≤ 6.5) will have unpredictable ratings (2 ≤ CHR ≤10) in flight. Sometimes the ground simulation C-H ratings have four ratings lower (more than one level of flying qualities) than in flight. Bad configurations (CHR >6.5) in MS-1 will be very bad configurations (CHR=10) in flight.

Fig. 9 shows the mean C-H ratings of flight and MS-1. The trends of the mean data are very similar to the median data. However, the median data groupings are more apparent than the

mean data. Fig. 10 and 11 show the difference (delta) in CHRs between flight and ground simulation. A positive delta indicates higher ratings (bad flying qualities) in flight than in the simulator. Configurations are ordered from best to worst based on median and mean CHR from flight. The vertical dashed lines separate the data into regions roughly equivalent to flying qualities levels.

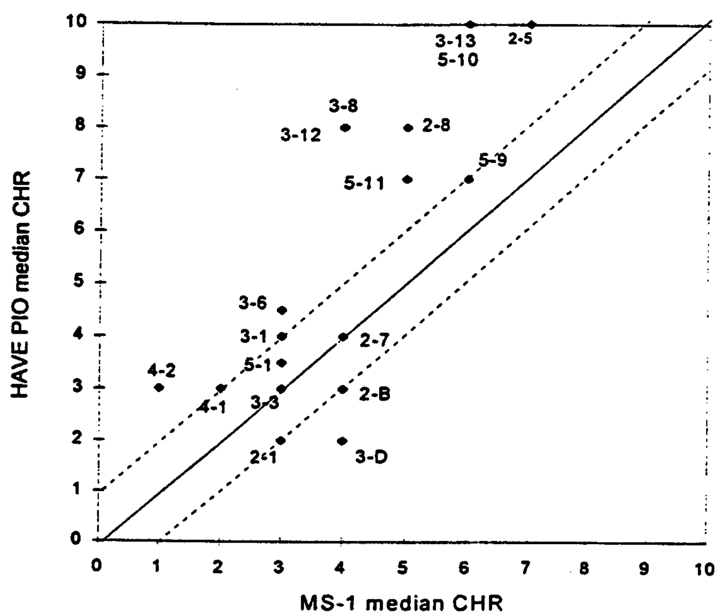


Fig. 8 MS-1vs.HAVE PIO in Median CHR

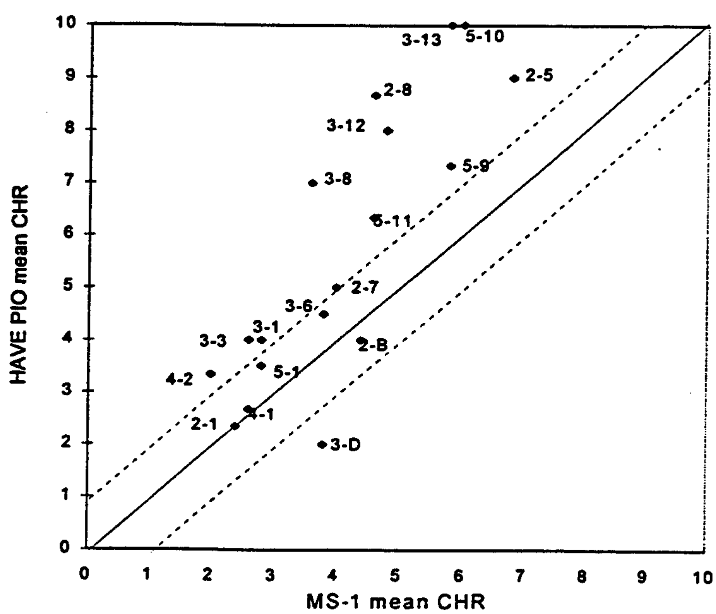


Fig. 9 MS-1 vs. HAVE PIO in Mean CHR

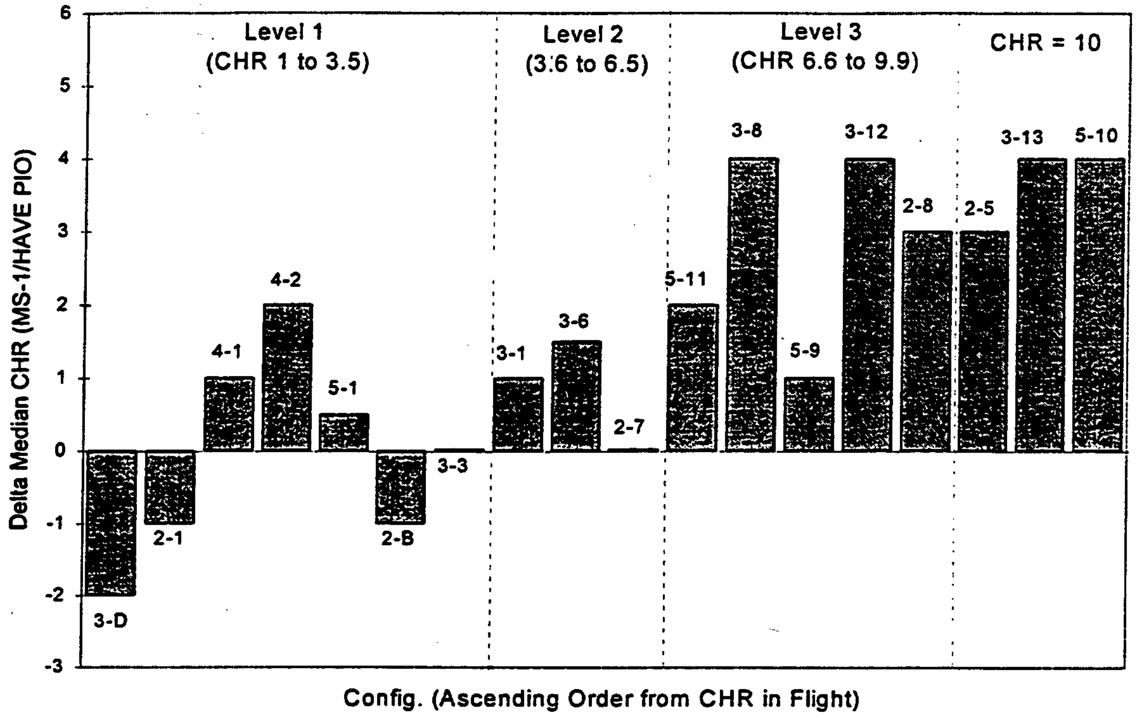


Fig. 10 MS-1/HAVE PIO in Median CHR Differences

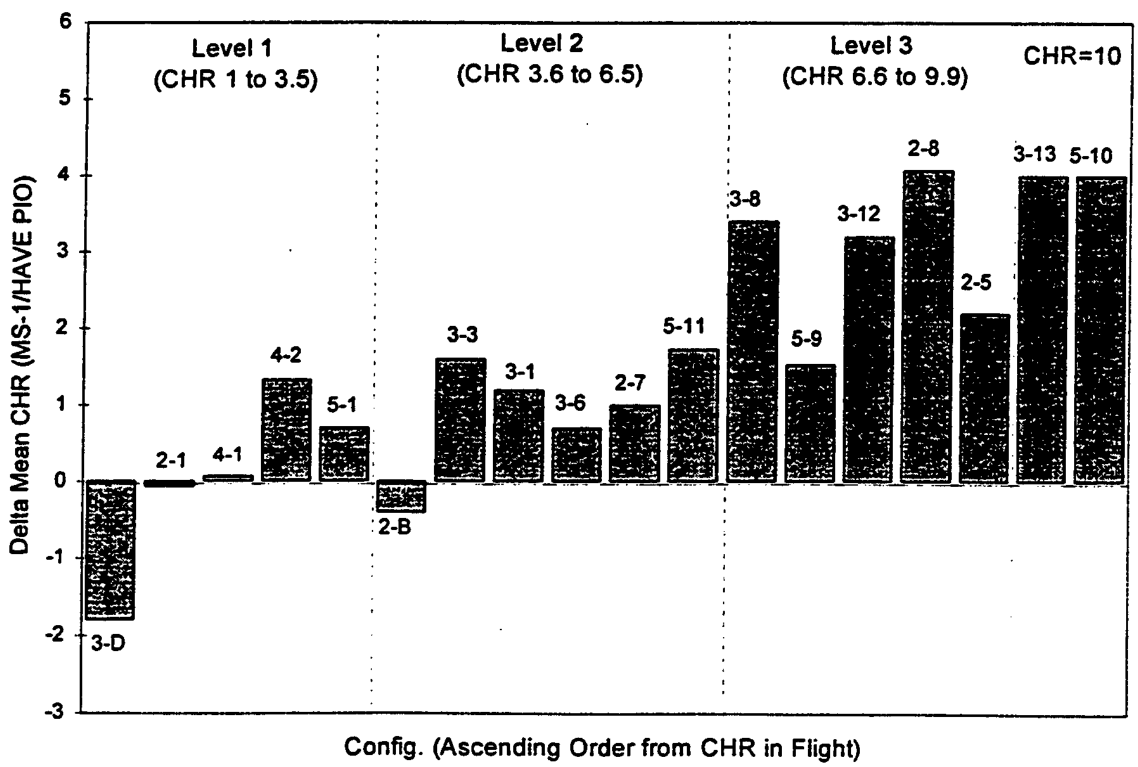


Fig. 11 MS-1/HAVE PIO in Mean CHR Differences

In Figures 12, and 13, the mean and median C-H ratings for each configuration from MS-1 are plotted against PIO ratings for the same configuration from HAVE PIO. Horizontal axis of the plots are mean and median CHRs of MS-1. The vertical axis of the plots are mean and median PIO ratings of HAVE PIO. In the landing task with no nonlinear effects, the configurations with mean or median CHRs $\leq$ 3 in MS-1 will probably have no PIO in flight. The configurations with mean or median CHRs $\geq$ 6 in MS-1 will probably have PIO in flight. The configurations with mean and median CHRs > 3 but < 6 in MS-1, prediction of flight PIO is non conclusive.

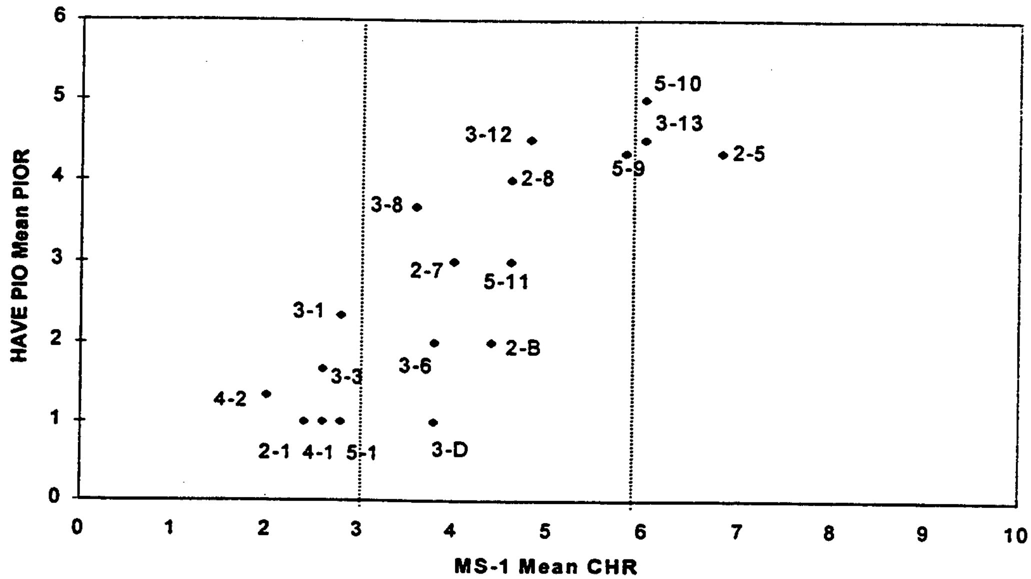


Fig. 12 MS -1 CHR vs. HAVE PIO PIOR in Mean

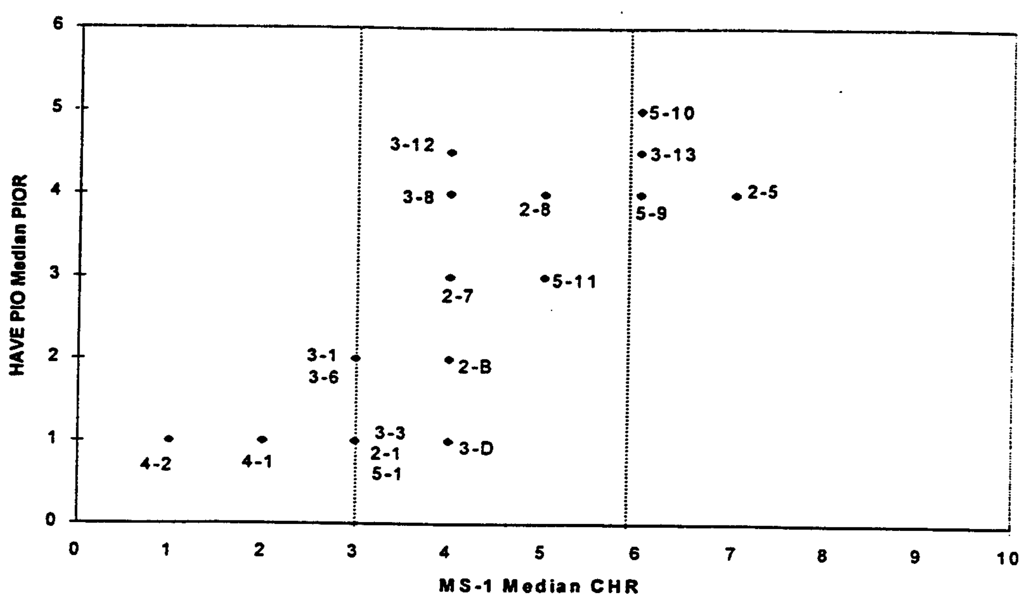


Fig. 13 MS -1 CHR vs. HAVE PIO PIOR in Median

5.2.2 LAMARS No Motion

Table 15 shows individual PIO ratings and statistical information for LAMARS no motion (LNM) and flight. Again, pilot ratings by different pilots are separated by slashes, multiple ratings by the same pilot are separated by commas. The dash (-) in the PIOR column means that pilot did not participate in the evaluation. As seen in MS-1 data, the PIO configurations in flight were seen by at least one pilot in LNM. For configurations 2-1, 3-6, and 5-1, at least one pilot saw an oscillation in ground simulation but had none in flight. Again, the pilots evaluated these three configurations on LNM as very sensitive configurations. The higher PIO ratings in LNM for these configurations resulted from the sensitivity.

Table 15: LNM and HAVE PIO PIOR Data

Conf.	PIOR flight	PIOR LNM	Mean flight	Mean LNM	Median flight	Median LNM	Std dev flight	Std dev LNM
2-B	3/2/2,1	2/1/4/4	2.00	2.75	2.00	3.00	0.58	1.50
2-1	1/1/1	1/1/4/2	1.00	2.00	1.00	1.50	0.00	1.41
2-5	4/4/5	3/1/3/4	4.33	2.75	4.00	3.00	0.58	1.26
2-7	4/3/2	2/1/4/3	3.00	2.50	3.00	2.50	1.00	1.29
2-8	4/4/4	4/2/3/2,1	4.00	2.75	4.00	2.50	0.00	0.96
3-D	1/1	2/2/3/3	1.00	2.50	1.00	2.50	0.00	0.58
3-1	3/2/2	1/1/2/2	2.33	1.50	2.00	1.50	0.00	0.58
3-3	3/1/1	1/1/2/1	1.67	1.25	1.00	1.00	1.15	0.50
3-6	2/-/2	1/1/4/3	2.00	2.25	2.00	2.00	0.00	1.50
3-8	4/3/4	2/2/4/5	3.67	3.25	4.00	3.00	0.58	1.50
3-12	4/5	4/1/3/4	4.50	3.00	4.50	3.50	0.71	1.41
3-13	4/5	3/1/2/4	4.50	2.50	4.50	2.50	0.71	1.29
4-1	1/1/1	2/1/1/1	1.00	1.25	1.00	1.00	0.00	0.50
4-2	1/1/2	1/1/2/2	1.33	1.50	1.00	1.50	0.58	0.58
5-1	1/-/1	1/1/2/4	1.00	2.00	1.00	1.50	0.00	1.41
5-9	4/5/4	4/2/4/5	4.33	3.75	4.00	4.00	0.58	1.26
5-10	5/-/5	4/3/4/5	5.00	4.00	5.00	4.00	0.00	0.82
5-11	2/4/3	2/1/3/4	3.00	2.50	3.0 0	2.50	1.00	1.29

The same trends observed in MS-1 appear in LNM. Figure 14 shows the median PIO ratings of flight and LNM. The median PIO ratings of 5 of the 18 configurations in flight were matched exactly by simulation. Ten of the 18 configurations in flight were within the error band. In general, the median data of LNM did show the same trends as in flight. However, they did not match the flight test results. Configurations 3-13 and 2-8 rated "undesirable motion" (PIOR=2.5) in ground simulation, were rated "PIO" (PIOR $\geq$ 4) in flight. The configuration 3-D rated "undesirable motion" (PIOR=2.5) in ground simulation was rated "no problem" (PIOR=1) in flight. Again, as mentioned earlier the high PIO rating for this configuration in LNM could be

caused by the stick sensitivity instead of the dynamics of the configuration. The good configurations rated "no PIO" (PIOR ≤ 2) in ground simulation, were rated "no PIO" (PIOR ≤ 2) in flight. The mediocre configurations (2 <PIOR ≤ 4) rated "undesirable motion" to oscillations in ground simulation could not be used to predict results in flight. The median PIO rating of these configurations were from 1 to 5 in flight. The worst configuration in flight (5-10) was also the worst configuration in ground simulation, but it was not as bad in LNM as it was in flight. Fig. 15 shows the mean PIO ratings of flight and LNM. The mean data showed similar trends and results as seen in the median PIO data. Figures 16 and 17 show the difference (delta) in median and mean PIO ratings.

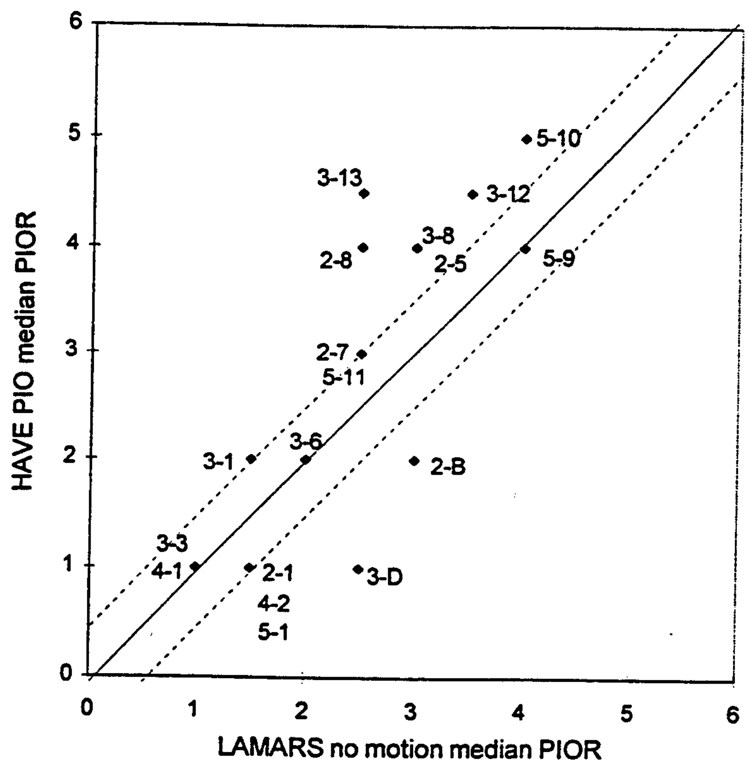


Fig. 14 LNM vs. HAVE PIO in Median PIOR

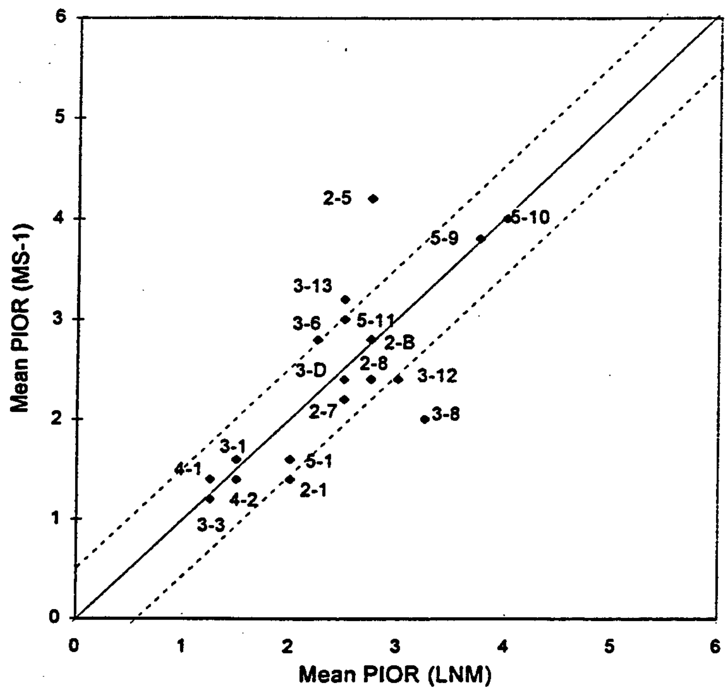


Fig. 15 LNM vs. HAVE PIO in Mean PIOR

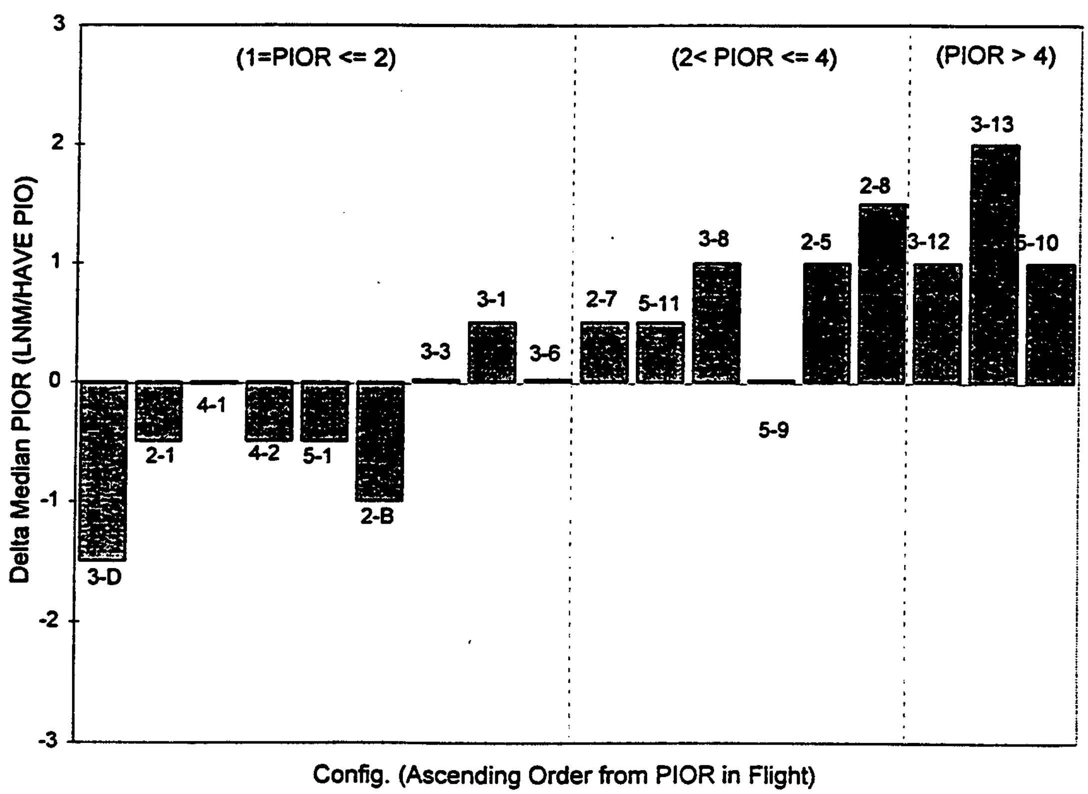


Fig. 16 LNM/HAVE PIO in Median PIOR Differences

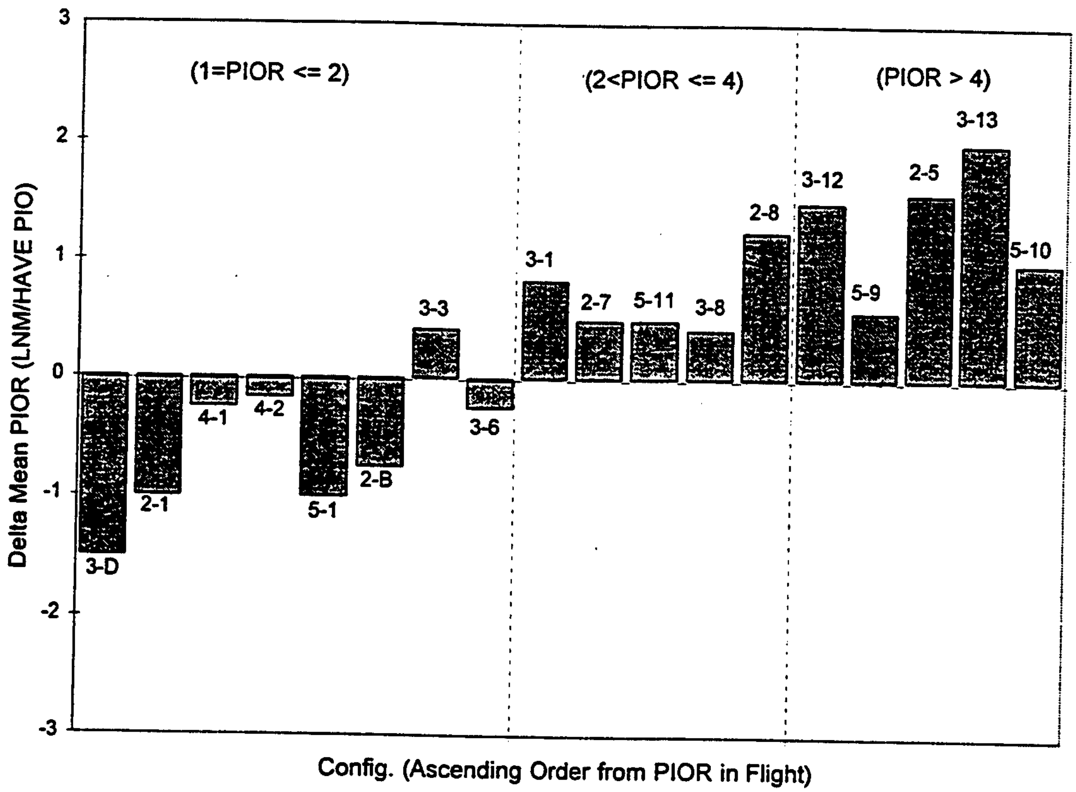


Fig. 17 LNM/HAVE PIO in Mean PIOR Differences

Table 16 shows the individual CH ratings and statistical information for LNM and HAVE PIO. Eleven of the 18 configurations had standard deviations near or below 1.25 for both flight and ground simulation. Fig. 18 shows the median CHR ratings of the 18 configurations. Nine of the 18 configurations in flight are outside the error band. Seven of those nine configurations had bad ratings in flight. The worst three configurations in flight were rated at least one handling qualities level better in LNM. The median data in CHR tended to gather into two groups as seen in MS-1 data. The first group of data contained all good and some mediocre configurations. The median CH ratings of these configurations were 5 or below in flight and ground simulation. The median CH ratings were clustered and correlated well. The second group of data contained all bad and some mediocre configurations. The median CH ratings of these configurations were 5 or above in ground simulation and 7 or above in flight. The median CH ratings did not correlate well . The simulation CH ratings sometimes had one flying quality level lower than in flight. Fig. 19 shows the mean CHR of the 18 configurations. The mean data showed similar trends and results as seen in the median data. Figures 20 and 21 show the difference (delta) in median and mean CH ratings.

Table 16: LNM and HAVE PIO CHR Data

Conf.	CHR flight	CHR LNM	Mean flight	Mean LNM	Median flight	Median LNM	Std dev flight	Std dev LNM
2-B	7/3/3,3	2/5/3/5	4.00	3.75	3.00	4.00	2.00	1.50
2-1	2/2/3	2/6/3/3	2.33	3.50	2.00	3.00	0.58	1.73
2-5	10/7/10	4/6/6/7	9.00	5.75	10.0	6.00	1.73	1.26
2-7	7/4/4	2/5/4/5	5.00	4.00	4.00	4.50	1.73	1.41
2-8	8/10/8	4/6/6/3,3	8.67	4.75	8.00	5.00	1.15	1.50
3-D	2/2	2/5/2/5	2.00	3.50	2.00	3.50	0.00	1.73
3-1	5/3/4	2/3/1/4	4.00	2.50	4.00	2.50	1.00	1.29
3-3	7/2/3	3/5/3/2	4.00	3.25	3.00	3.00	2.65	1.26
3-6	5/4	3/6/4/5	4.50	4.50	4.50	4.50	0.71	1.29
3-8	8/5/8	3/6/4/7	7.00	5.00	8.00	5.00	1.73	1.83
3-12	7/9	5/7/6/7	8.00	6.25	8.00	6.50	1.41	0.96
3-13	10/10	5/3/7/5	10.0	5.00	10.0	5.00	0.00	1.63
4-1	3/2/3	1/2/3/2	2.67	2.00	3.00	2.00	0.58	0.82
4-2	3/3/4	3/4/4/3	3.33	3.50	3.00	3.50	0.58	0.58
5-1	2/5	3/4/2/5	3.50	3.50	3.50	3.50	2.12	1.29
5-9	7/8/7	4/6/6/7	7.33	5.75	7.00	6.00	0.58	1.26
5-10	10/10	7/8/6/7	10.0	7.00	10.0	7.00	0.00	0.82
5-11	7/7/5	3/6/5/5	6.33	4.75	7.00	5.00	1.15	1.26

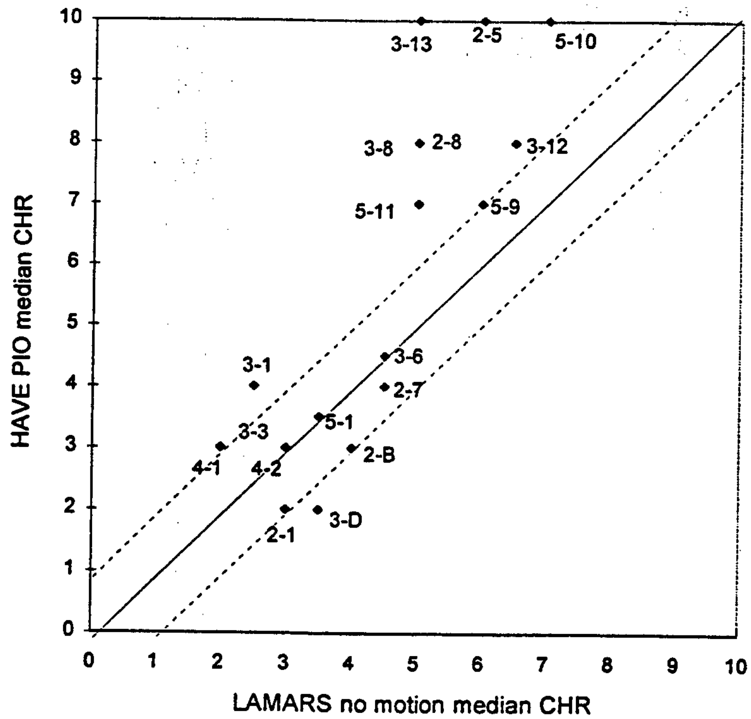


Fig. 18 LNM vs. HAVE PIO in Median CHR

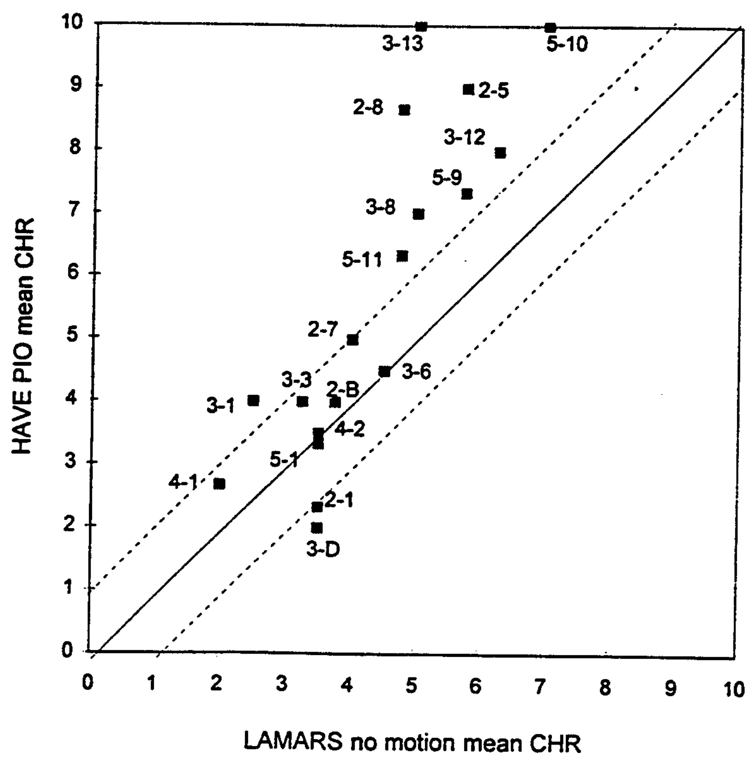


Fig. 19 LNM vs. HAVE PIO in Mean CHR

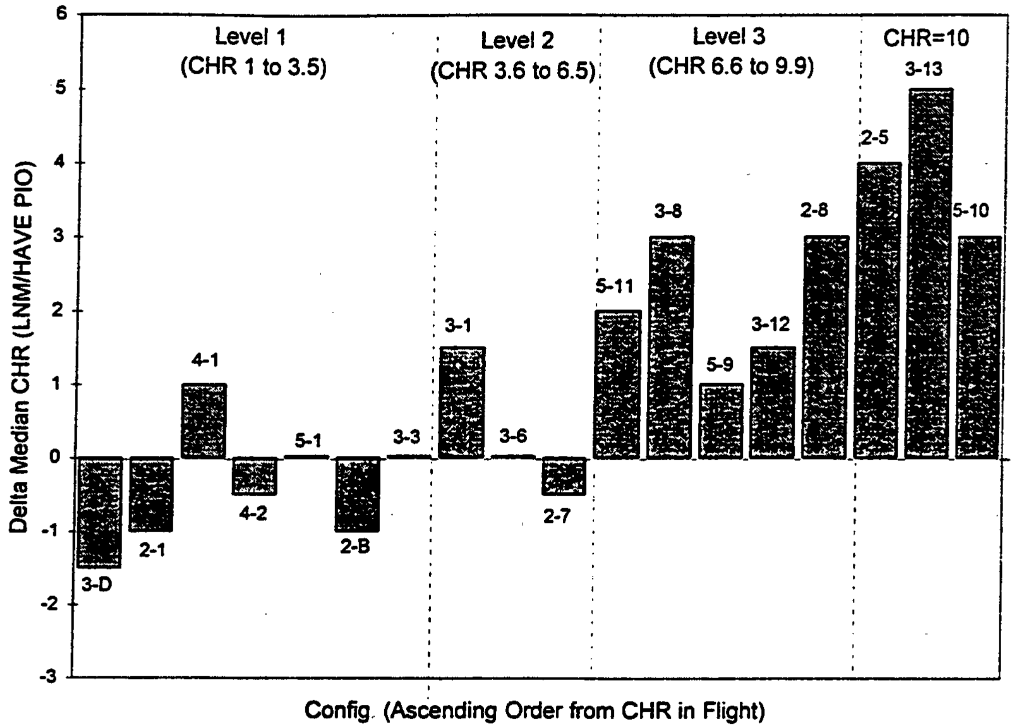


Fig. 20 LNM/HAVE PIO in Median CHR Differences

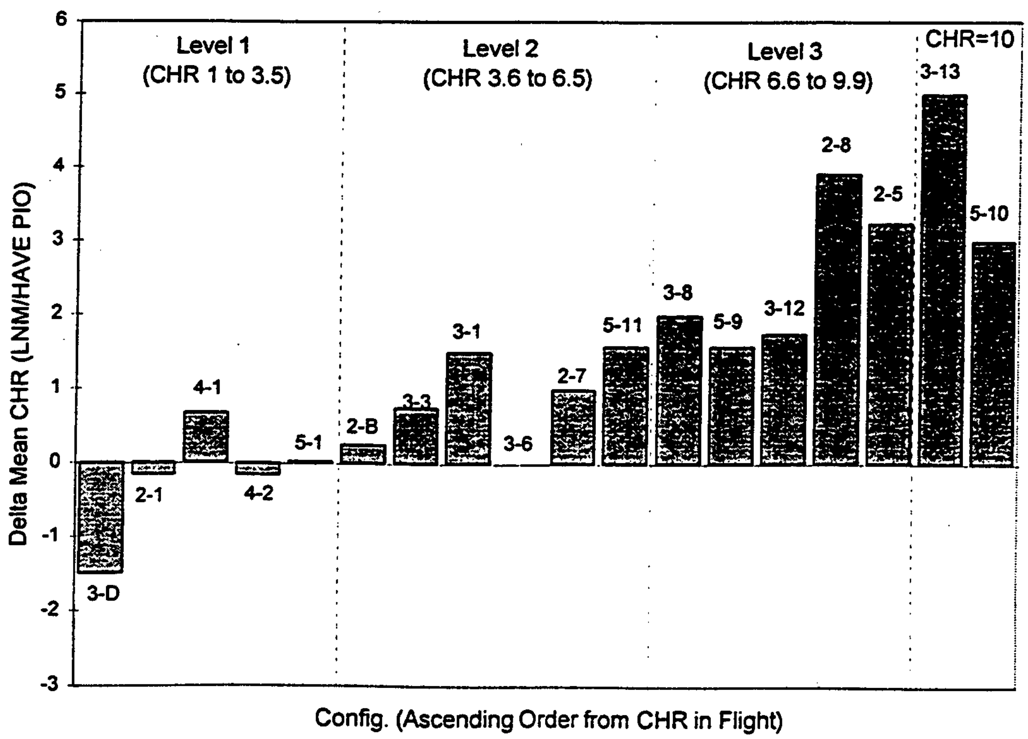


Fig. 21 LNM/HAVE PIO in Mean CHR Differences

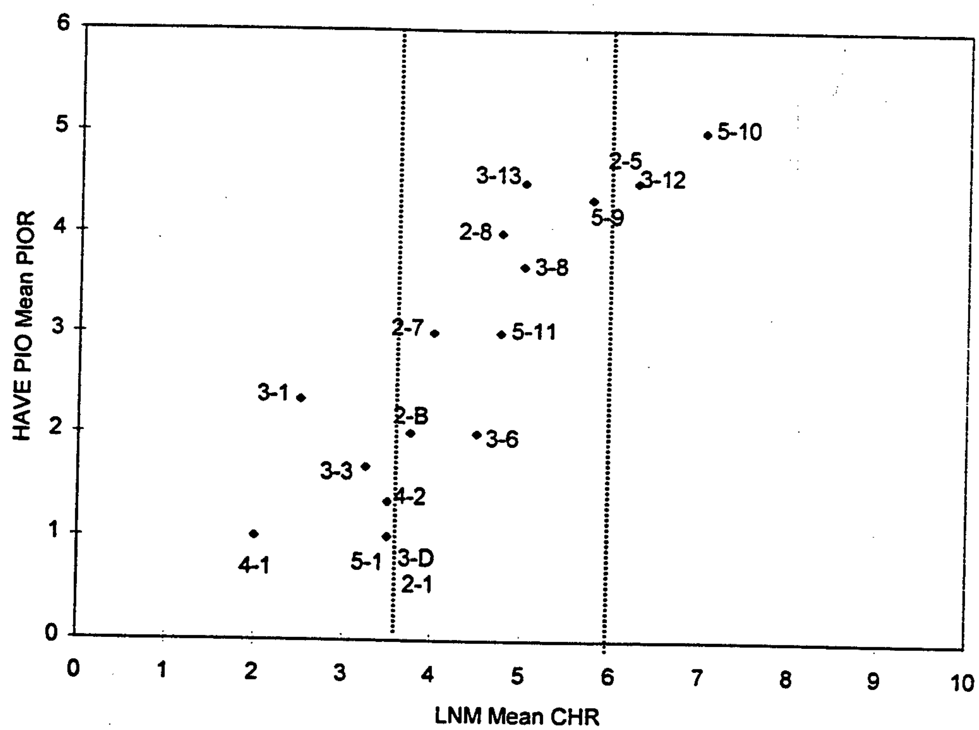


Fig. 22 LNM CHR vs. HAVE PIO PIOR in Mean

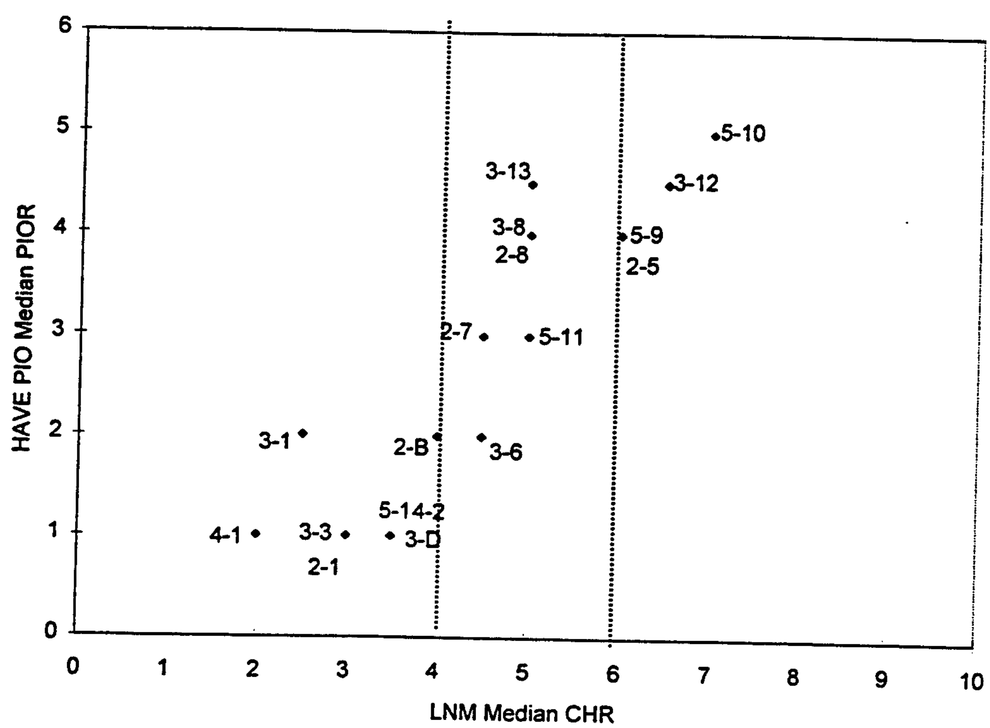


Fig. 23 LNM CHR vs. HAVE PIO PIOR in Median

In Figures 22, and 23, the mean and median C-H ratings for each configuration from LNM are plotted against PIO ratings for the same configurations from HAVE PIO. Horizontal axis of the plots are mean and median CH ratings of LNM. The vertical axis of the plots are mean and median PIO ratings of HAVE PIO. In the landing task with no nonlinear effects, the configurations with mean CHR $\leq$ 3.5 or median CHR $\leq$ 4 in LNM will probably have no PIO in flight. The configurations with mean or median CHRs $\geq$ 6 in LNM will probably have PIO in flight. The configurations with mean or median CHRs > 3.5 but < 6 in LNM, prediction of flight PIO is non conclusive

5.2.3 LAMARS Motion

The "standard" linear motion gain was used during HAVE PIO evaluation. Recently, a motion gain study was conducted in LAMARS motion (LM). Figures E1, E2 and E3 in Appendix E show the acceleration response of LAMARS with different gain sets. The solid line of the plot represented the acceleration response with respect to the pilot input of the HAVE PIO configuration 5-10 at the accelerometer where the pilot sits. The dashed line of the plot represented the acceleration response of the model. Figure E1 shows the acceleration response of the configuration 5-10 in LAMARS with the "standard" linear motion gain set which was used during the HAVE PIO. Figure E1 also shows the problems in the magnitude and phase of the acceleration response between the model and the accelerometer with the linear motion gain. The motion gain may cause a problem in terms of data correlation. There are no conclusions about this. What the data showed were small differences in pilot ratings between LAMARS motion and no motion. During Phase I of HAVE PIO evaluation, one of five pilots did not like the motion of LAMARS with the "standard" linear motion gain set. His complaint was the motion confused him more than helping him in terms of the aircraft response. Figure E2 shows the acceleration response of LAMARS with the improved linear motion gain. With this gain set, the phase problem was improved, but not the magnitude. Figure E3 shows that the problems in phase lag and magnitude were improved with the adaptive motion gain. A preliminary evaluation has been completed with an improved linear motion gain with some positive comments from pilots about the motion. More testing will be done with the improved motion gain sets at a later date.

The same trends observed in MS-1 and LMN for LM. Table 17 shows individual PIO ratings and statistical information of the 18 configurations for both LM and HAVE PIO. With the exception of configurations 3-8, 2-8 and 2-7, PIO configurations in which PIOs were seen in flight resulted in PIOs seen at least by one pilot in LM. In LM, some pilots noticed "undesirable motions" for these configurations when they attempted tight controls, but "no oscillations" as seen in flight. The configuration 5-1 had "oscillations" on LM, but had none in flight. One pilot evaluated configuration 5-1 as a sluggish configuration and it required a high level of pilot compensation to keep out of PIO problems.

Table 17: LM and HAVE PIO PIOR Data

Conf	PIOR flight	PIOR LM	Mean flight	Mean LM	Median flight	Median LM	Std dev flight	Std dev LM
2-B	3/2/2,1	2/2/2/2	2.00	2.00	2.00	2.00	0.58	0.00
2-1	1/1/1	1/1/1/2	1.00	1.25	1.00	1.00	0.00	0.50
2-5	4/4/5	2/4/4	4.33	3.33	4.00	4.00	0.58	1.15
2-7	4/3/2	3/3/1	3.00	2.33	3.00	3.00	1.00	1.15
2-8	4/4/4	4,1/3/3	4.00	3.33	4.00	3.00	0.00	0.58
3-D	1/1	2/1/1/1	1.00	1.25	1.00	1.00	0.00	0.50
3-1	3/2/2	1/3/1/3	2.33	2.00	2.00	2.00	0.58	1.15
3-3	3/1/1	2/1/1	1.67	1.33	1.00	1.00	1.15	0.58
3-6	2/-/2	2/2/3	2.00	2.33	2.00	2.00	0.00	0.58
3-8	4/3/4	3/3/1	3.67	2.33	4.00	3.00	0.58	1.15
3-12	4/5	1/3/4/4	4.50	3.00	4.50	3.50	0.71	1.41
3-13	4/5	4/4/2	4.50	3.33	4.50	4.00	0.71	1.15
4-1	1/1/1	1/2/1	1.00	1.33	1.00	1.00	0.00	0.58
4-2	1/1/2	3/1/1	1.33	1.67	1.00	1.00	0.58	1.15
5-1	1/-/1	4/3/1	1.00	2.67	1.00	3.00	0.00	1.53
5-9	4/5/4	4/4/4	4.33	4.00	4.00	4.00	0.58	0.00
5-10	5/-/5	4/4/5/4	5.00	4.25	5.00	4.00	0.00	0.50
5-11	2/4/3	3/4/1	3.00	2.67	3.00	3.00	1.00	1.53

In Fig. 24, the median PIO ratings of the 18 configurations from LM are plotted against PIO ratings for the same configurations from HAVE PIO. The median PIO ratings of 12 configurations in flight were matched exactly by the median PIO ratings of LM. Configurations rated "no PIO" in flight (PIOR $\leq$ 2) were rated "no PIO" in LM with the exception of the configuration 5-1. Three pilots who flew this configuration in LM gave PIOR of 4, 3 and 1. Two pilots complained about the airspeed control and the slow and unpredictable pitch response of the configuration. However, one pilot did not have any problems with this configuration. Configurations rated "undesirable motion" to "oscillation" in ground simulation (2<PIOR $\leq$ 4) were "unpredictable" in flight. In other words, the median PIO rating of these configurations was between 2 and 4 in LM will be from 1 to 5 in flight. The worst configuration in flight (5-10) was one of the worst configurations in LM; however, it was not as bad in LM as it was in flight.

In Fig. 25, the mean PIO ratings for the 18 configurations from LM are plotted against PIO ratings for the same configurations from HAVE PIO. In general, the mean data in LM shows the same trends as seen in flight. However, the mean data were a little more scattered than the median data. Non-PIO configurations (PIOR $\leq$ 2) in flight tended to be non-PIO configurations in LM.

The observation here is very close to the one that was made for the median data of LM. Figures 26 and 27 show the difference (delta) in the median and mean PIO ratings.

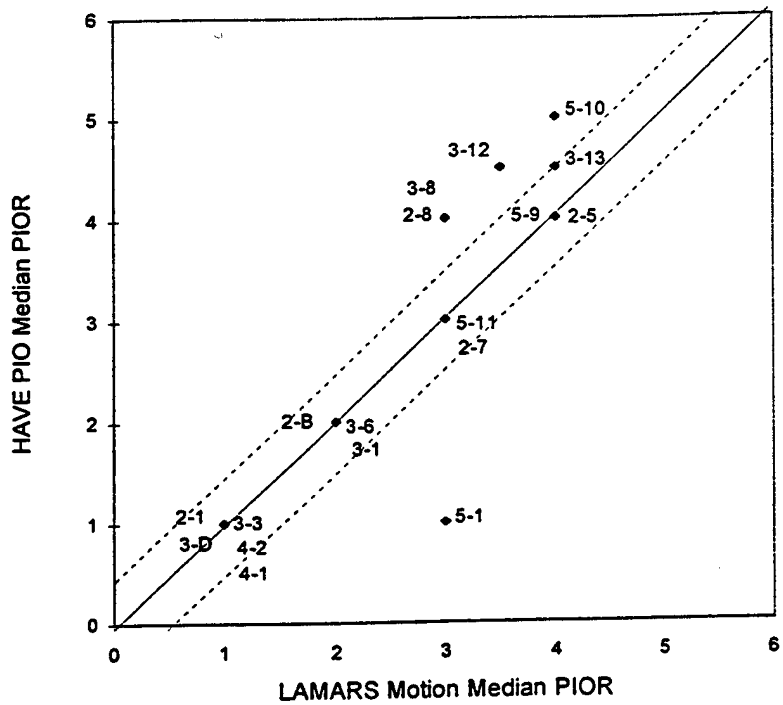


Fig. 24 LM vs. HAVE PIO in median PIOR

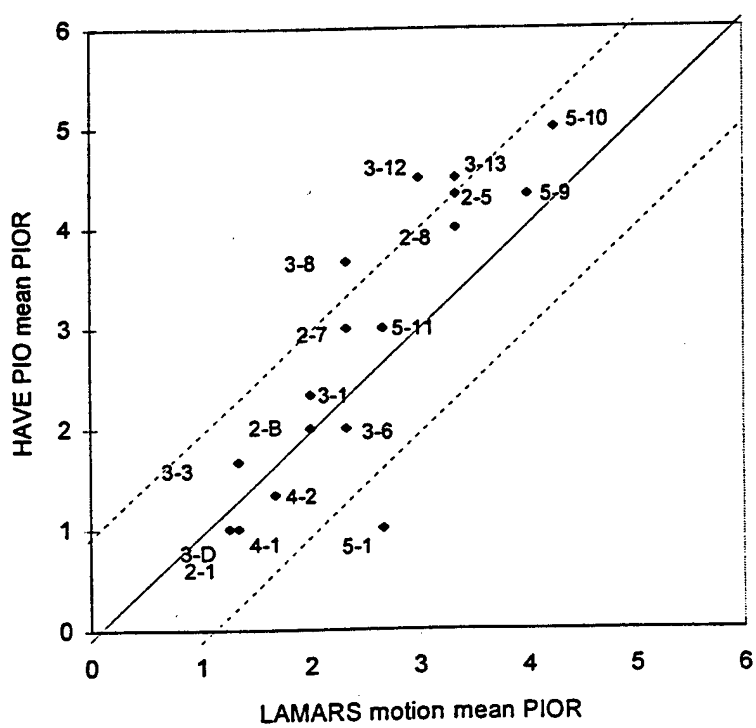


Fig. 25 LM vs. HAVE PIO in Mean PIOR

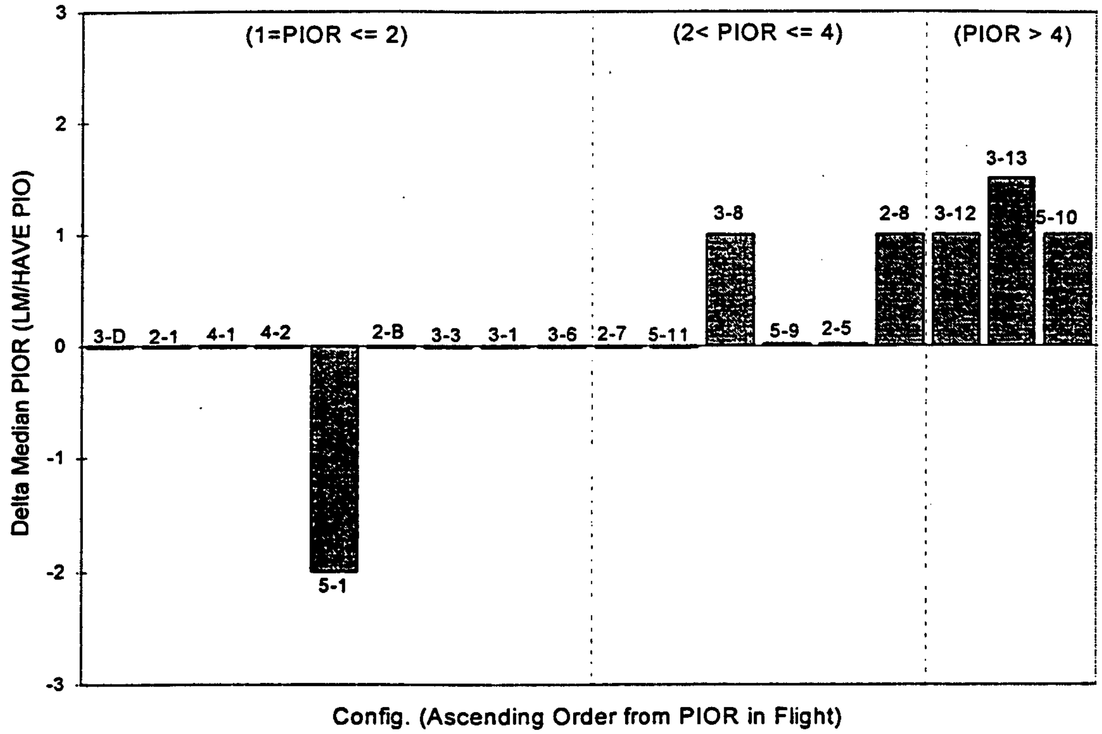


Fig. 26 LM/HAVE PIO in Median PIOR Differences

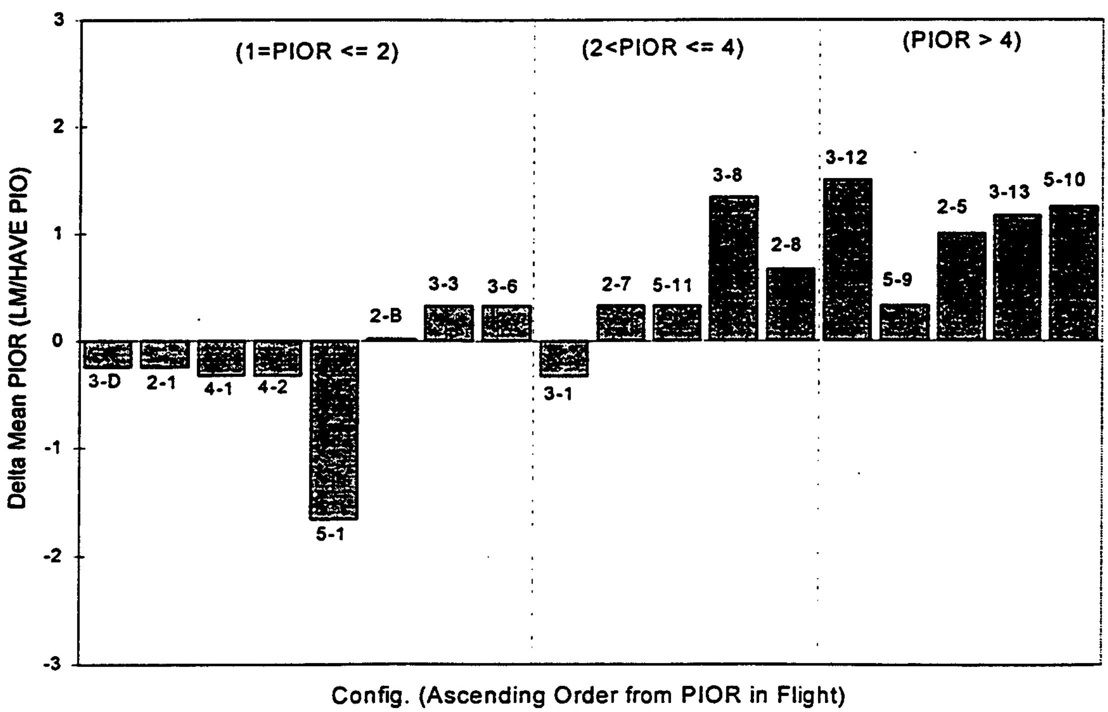


Fig. 27 LM/HAVE PIO in Mean PIOR Differences

Table 18 shows individual CH ratings and statistical information for both LM and HAVE PIO.

Table 18: LM and HAVE PIO CHR Data

Conf.	CHR flight	CHR LM	Mean flight	Mean LM	Median flight	Median LM	Std dev flight	Std dev LM
2-B	7/3/3,3	3/4/4/4	4.00	3.75	3.00	4.00	2.00	0.50
2-1	2/2/3	2/1/2/3	2.33	2.00	2.00	2.00	0.58	0.82
2-5	10/7/10	4/6/6	9.00	5.33	10.0	6.00	1.73	1.15
2-7	7/4/4	5/5/3	5.00	4.33	4.00	5.00	1.73	1.15
2-8	8/10/8	5,5/5/5	8.67	5.00	8.00	5.00	1.15	0.00
3-D	2/2	3/3/2/3	2.00	2.75	2.00	3.00	0.00	0.50
3-1	5/3/4	1/5/3/5	4.00	3.50	4.00	4.00	1.00	1.91
3-3	7/2/3	2/2/1	4.00	1.67	3.00	2.00	2.65	0.58
3-6	5/4	2/4/5	4.50	3.67	4.50	4.00	0.71	1.53
3-8	8/5/8	6/5/3	7.00	4.67	8.00	5.00	1.73	1.53
3-12	7/9	4/6/7/7	8.00	6.00	8.00	6.50	1.41	1.41
3-13	10/10	6/7/5	10.0	6.00	10.0	6.00	0.00	1.00
4-1	3/2/3	3/4/3	2.67	3.33	3.00	3.00	0.58	0.58
4-2	3/3/4	3/5/2	3.33	3.33	3.00	3.00	0.58	1.53
5-1	2/5	7/5/4	3.50	5.33	3.50	5.00	2.12	1.53
5-9	7/8/7	7/7/6	7.33	6.67	7.00	7.00	0.58	0.58
5-10	10/10	7/8/8/6	10.00	7.25	10.0	7.50	0.00	0.96
5-11	7/7/5	4/6/2	6.33	4.00	7.00	4.00	1.15	2.00

In Figure 28, the median CH ratings for each configuration from LM were plotted against the median CH ratings for the same configuration from HAVE PIO. The median CH ratings of the 18 configurations tended to gather into two groups as seen in MS-1 and LNM. A first group of data contained all good and some mediocre configurations. The median CH ratings of these configurations matched flight ratings very well. These configurations clustered in the region where the CH ratings were 5 or below for both flight and ground simulation. The second group of data contained all bad and some mediocre configurations. The median CH ratings of these configurations did not match the ratings in flight. The median CH ratings of these configurations clustered in the region where the median CH ratings of 4.5 or above in LM and 7 or above in flight. In general, the median CH ratings of the ground simulation did not match flight test results. However, the simulation data show the same trends as seen in flight. Figure 29 shows the mean CH ratings of LM and HAVE PIO. Similar trends and results were observed in mean CH ratings as seen in the median data. Figures 30 and 31 show the difference (delta) in median and mean CH ratings of LM.

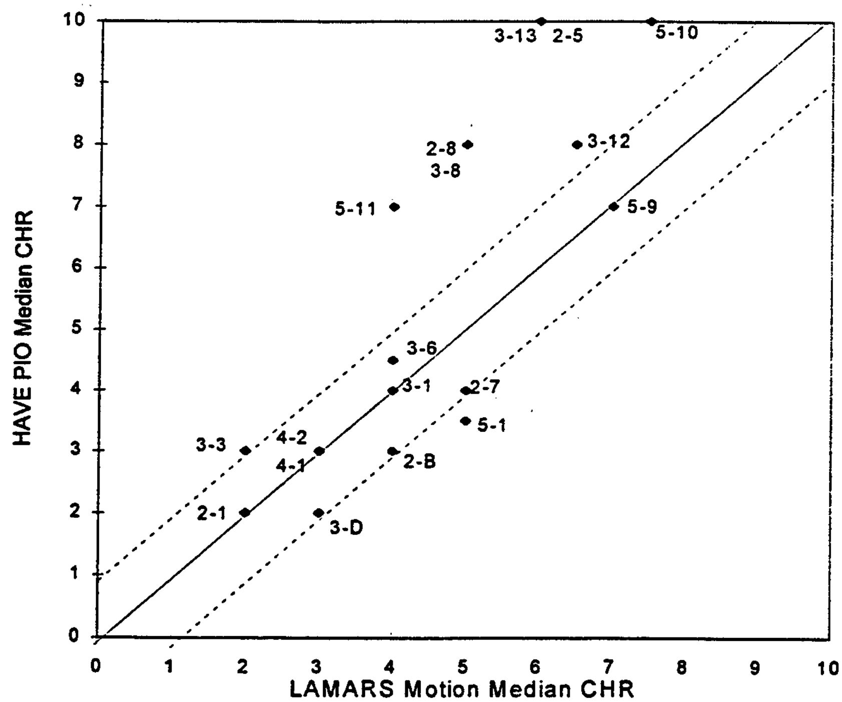


Fig. 28 LM vs. HAVE PIO in Median CHR

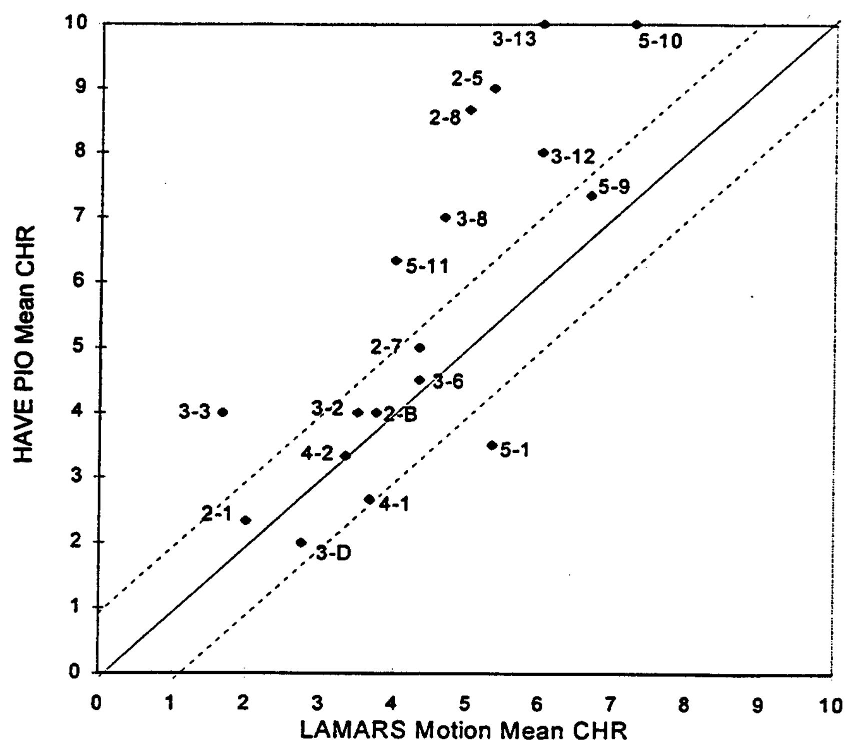


Fig. 29 LM vs. HAVE PIO in Mean CHR

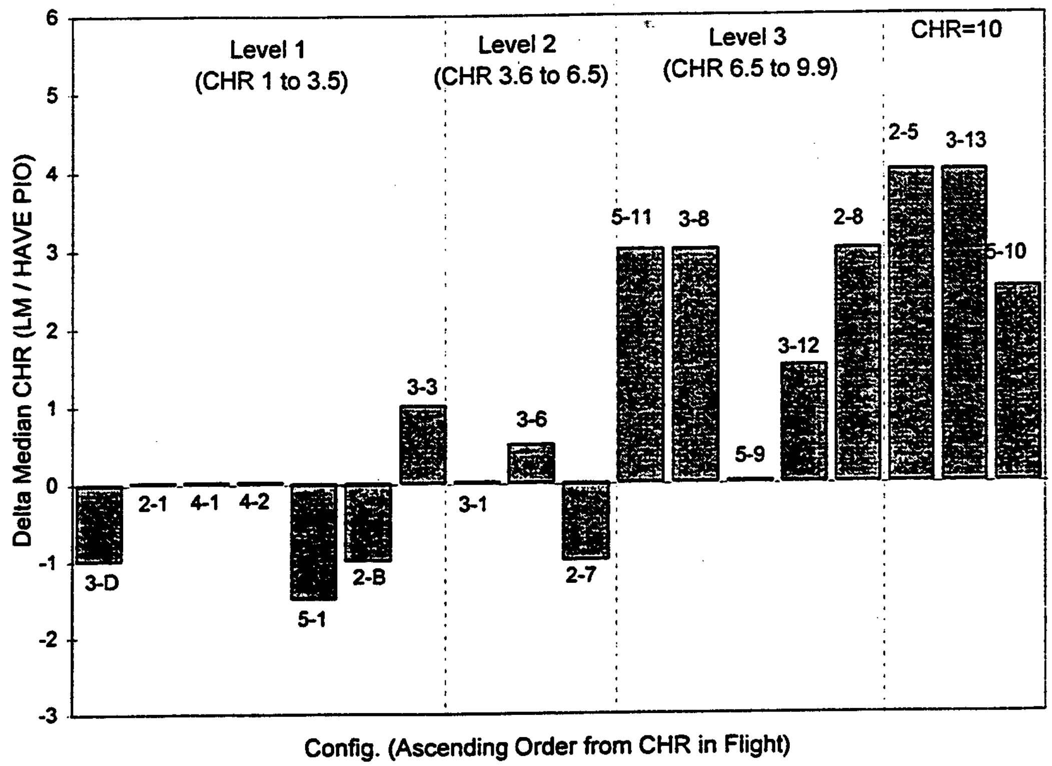


Fig. 30 LM/HAVE PIO in Median CHR Differences

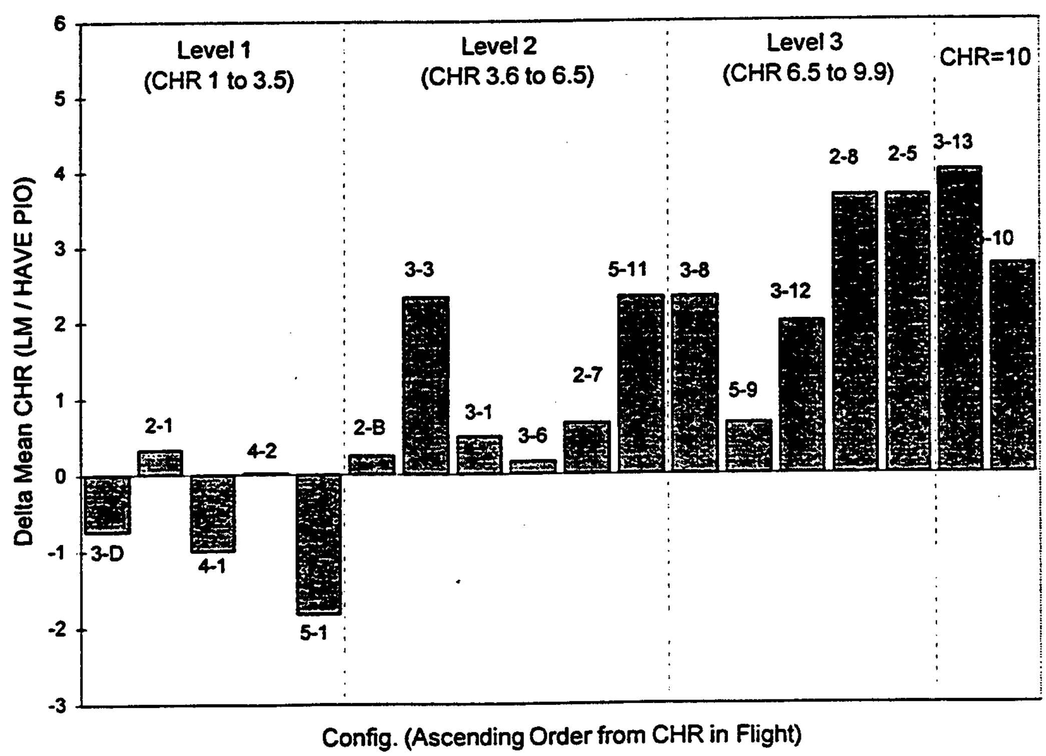


Fig. 31 LM/HAVE PIO in Mean CHR Differences

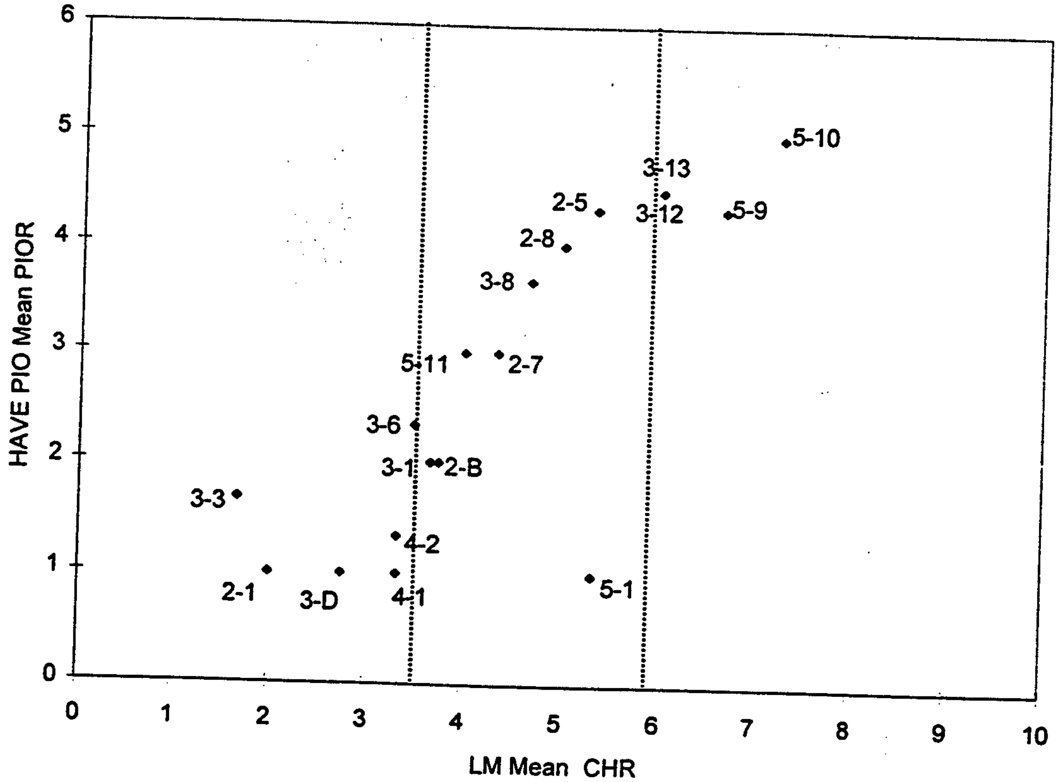


Fig. 32 LM CHR vs. HAVE PIO PIOR in Mean

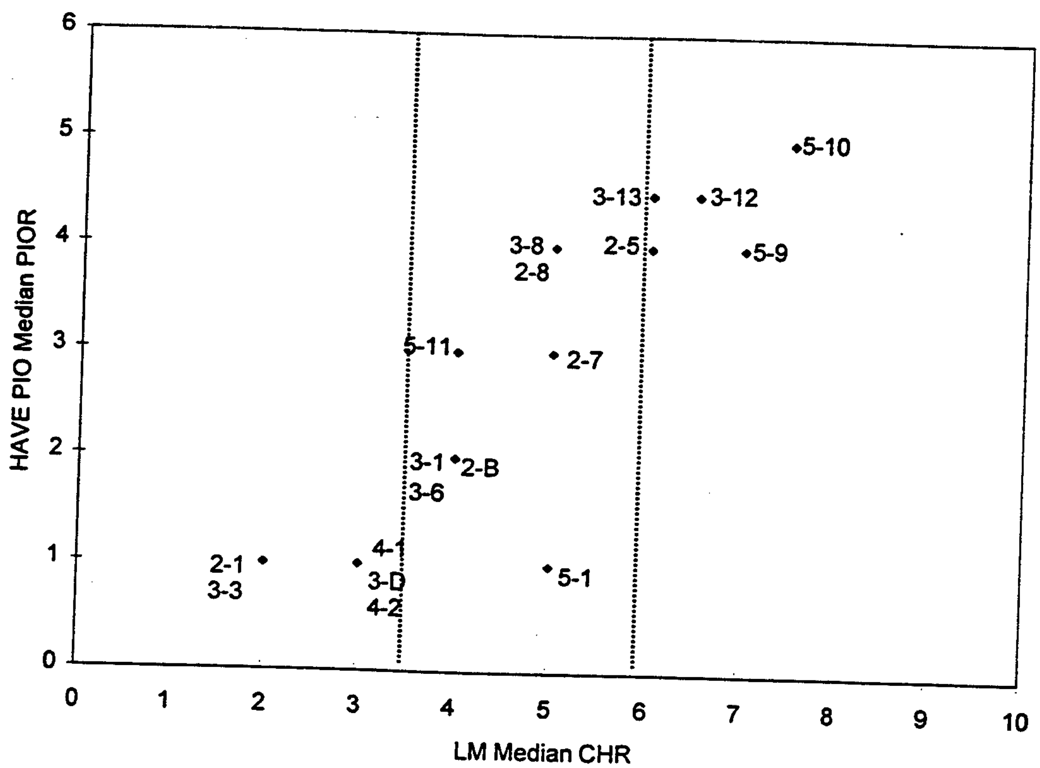


Fig. 33 LM CHR vs. HAVE PIO PIOR in Median

In Figures 32, and 33, the mean and median C-H ratings for each configuration from LM are plotted against PIO ratings for the same configurations from HAVE PIO. Horizontal axis of the plots are mean and median CH ratings of LM. The vertical axis of the plots are mean and median PIO ratings of HAVE PIO. In the landing task with no nonlinear effects, the configurations with mean or median CHRs $\leq$ 3.5 in LM will probably have no PIO in flight. The configurations with mean or median CHRs $\geq$ 6 in LM will probably have PIO in flight. The configurations with mean or median CHRs > 3.5 but < 6 in LM, prediction of flight PIO is non conclusive

5.2.4 MS-1 versus LAMARS No Motion

Since there was not much difference in the pilot ratings between LNM and LM, the author chose to compare pilot ratings between LNM and MS-1. As alluded to previously, the same trends were seen in both MS-1 and LAMARS. This section compares the two simulators directly. physical differences between the simulators are primarily the size of the dome, field-of-view, resolution, contrast, and luminance as shown in LAMARS and MS-1 sections.

Table 19 shows the individual PIO ratings and statistical information for MS-1 and LNM.

Table 19: MS-1 and LNM PIOR Data

Conf.	PIOR MS-1	PIOR LNM	Mean MS-1	Mean LNM	Median MS-1	Median LNM	Std dev MS-1	Std dev LNM
2-B	2/2/4/4,4/2	2/1/4/4	2.80	2.75	2.00	3.00	1.10	1.50
2-1	1/1/2/1/2	1/1/4/2	1.40	2.00	1.00	1.50	0.55	1.41
2-5	4/4/4/4/5	3/1/3/4	4.20	2.75	4.00	3.00	0.45	1.26
2-7	2/1/3/1/4	2/1/4/3	2.20	2.50	2.00	2.50	1.30	1.29
2-8	4/1/4/1/2	4/2/3/2	2.40	2.75	2.00	2.50	1.52	0.96
3-D	2/1/3/2/4	2/2/3/3	2.40	2.50	2.00	2.50	1.14	0.58
3-1	1/2/2/1/2	1/1/2/2	1.60	1.50	2.00	1.50	0.55	0.58
3-3	1/1/1/1,1/2	1/1/2/1	1.20	1.25	1.00	1.00	0.45	0.50
3-6	4/2/2/2/4	1/1/4/3	2.80	2.25	2.00	2.00	1.10	1.50
3-8	2/2/2/2/2,1	2/2/4/5	2.00	3.25	2.00	3.00	0.00	1.50
3-12	4/1/2/4/1	4/1/3/4	2.40	3.00	2.00	3.50	1.52	1.41
3-13	4/2/5/3/2,4	3/1/2/4	3.60	2.50	4.00	2.50	1.14	1.29
4-1	1/1/2/1,1/2	2/1/1/1	1.40	1.25	1.00	1.00	0.55	0.50
4-2	1/1/1/1/3	1/1/2/2	1.40	1.50	1.00	1.50	0.89	0.58
5-1	3/1/1/1/2	1/1/2/4	1.60	2.00	1.00	1.50	0.89	1.41
5-9	4/2/4/4/5	4/2/5/4	3.80	3.75	4.00	4.00	1.10	1.26
5-10	4/4/4/4/4,4	4/3/4/5	4.00	4.00	4.00	4.00	0.00	0.82
5-11	4/2,1/2/2/5	2/1/3/4	3.00	2.50	2.00	2.50	1.41	1.29

Fig. 34 shows the median PIO ratings of the 18 configurations of LNM and MS-1. In general, the median PIO ratings of the 18 configurations had good correlation between the two simulators with the exception of configurations 3-12, 3-8, 2-5 and 2-B. Pilots rated configuration 2-5 one PIO rating higher in MS-1 than in LNM. Pilots rated configurations 3-12, 2-B and 3-8 from 1 to 1.5 PIO ratings higher in LAMARS than in MS-1. Some differences in PIO ratings between two simulators could come from a pilot variability or the visual displays of the two systems. More studies about the differences in ratings between two simulators should be pursued in order to determine the causes.

Fig. 35 shows the mean PIO ratings of the 18 configurations of LNM and MS-1. In general, the mean PIO ratings of the 18 configurations had good correlation between the two simulators with the exception of configurations 2-5 and 3-8. Most of the ratings were in the band. This was slightly better correlation than the median data.

Fig. 36 and 37 show the differences (delta) between the two simulators in terms of mean and median PIO ratings. A positive delta indicates higher ratings in LNM than in MS-1. Configurations are ordered from best to worst based on median and mean PIOR from flight. The vertical dashed lines separate the data into regions roughly equivalent to flying qualities Levels.

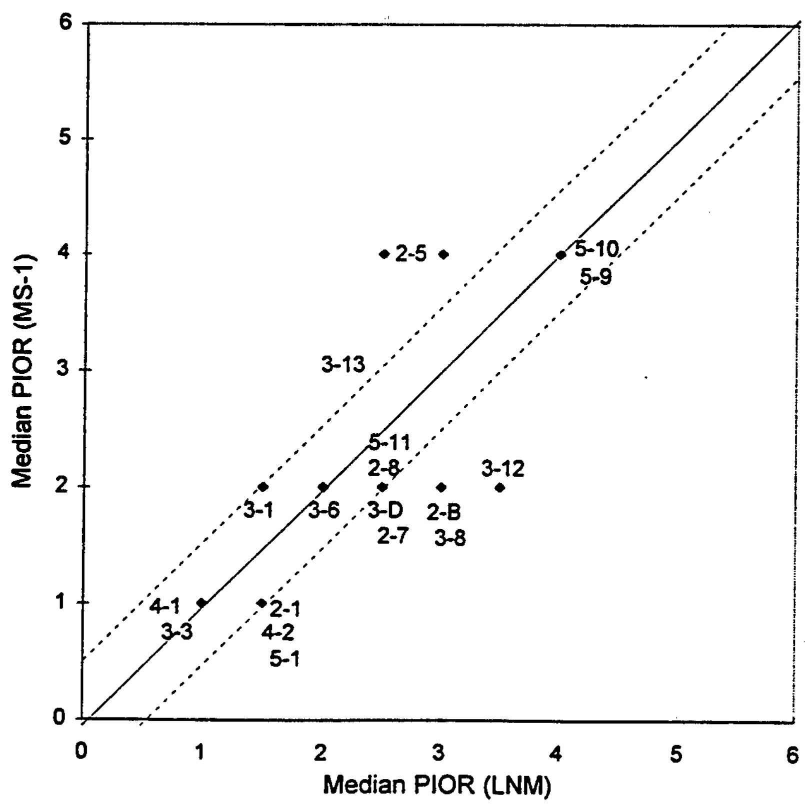


Fig. 34 MS-1 vs. LNM in Median PIOR

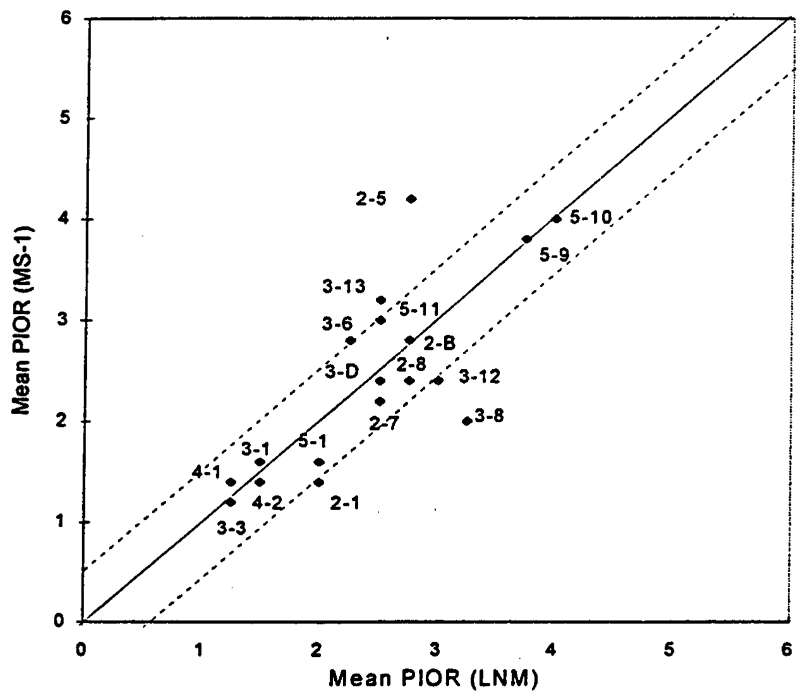


Fig 35 MS-1 vs. LNM in Mean PIOR

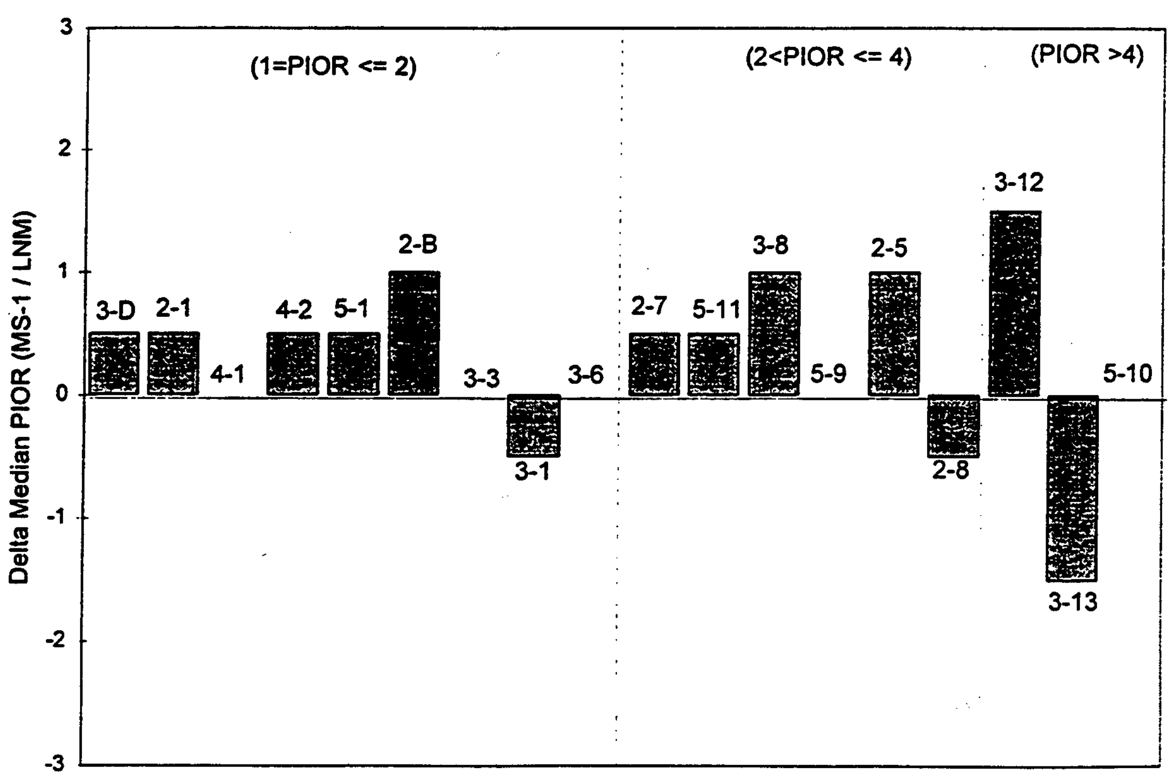


Fig. 36 MS-1 /LNM in Median PIOR Differences

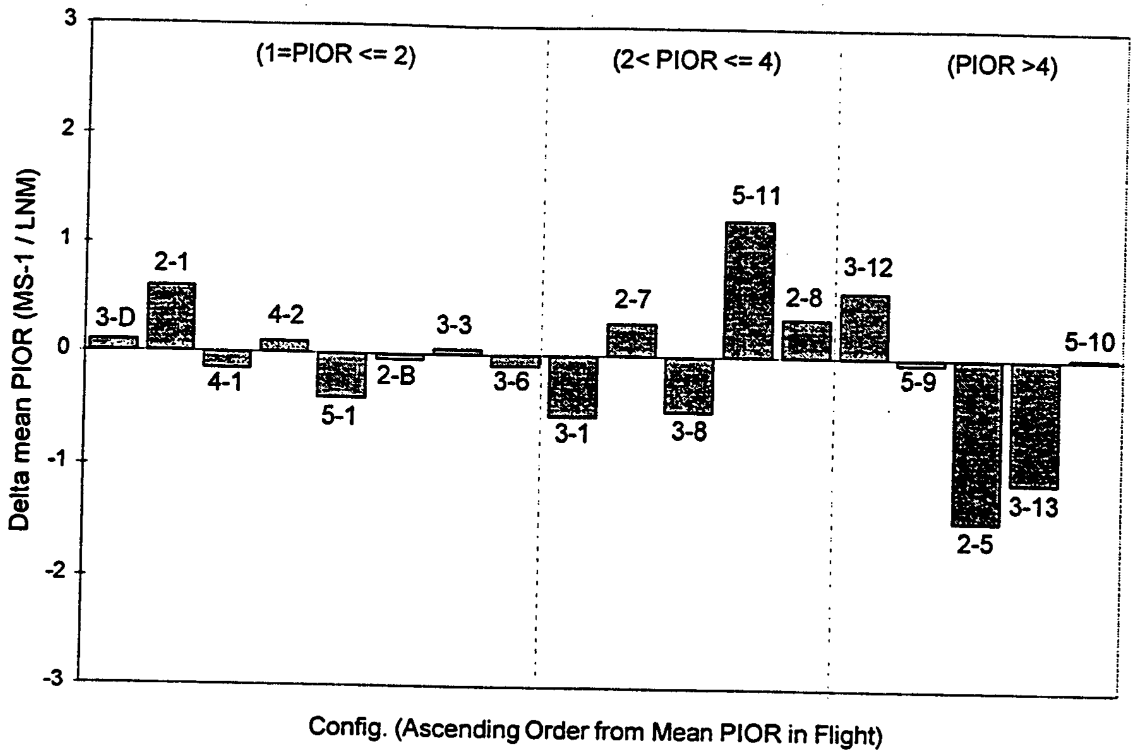


Fig. 37 MS-1 / LNM in Mean PIOR Differences

Table 20 shows the individual CHR and the statistical information for MS-1 and LNM.

Table 20: MS-1 and LNM CHR data

Conf.	CHR MS-1	CHR LNM	Mean MS-1	Mean LNM	Median MS-1	Median LNM	Std dev MS-1	Std dev LNM
2-B	4/3/6/5,4/4	2/5/3/5	4.40	3.75	4.00	4.00	1.14	1.50
2-1	1/1/4/3/3	2/6/3/3	2.40	3.50	3.00	3.00	1.34	1.73
2-5	7/7/7/7/6	4/6/6/7	6.80	5.75	7.00	6.00	0.45	1.26
2-7	2/4/5/5/4	2/5/4/5	4.00	4.00	4.00	4.50	1.22	1.41
2-8	5/3/6/4/5	4/6/6/3,3	4.60	4.75	5.00	5.00	1.14	1.50
3-D	3/2/5/5/4	2/5/2/5	3.80	3.50	4.00	3.50	1.30	1.73
3-1	2/3/4/3/2	2/3/1/4	2.80	2.50	3.00	2.50	0.84	1.29
3-3	3/3/1/3,4/2	3/5/3/2	2.60	3.25	3.00	3.00	1.14	1.26
3-6	3/3/3/5/5	3/6/4/5	3.80	4.50	3.00	4.50	1.10	1.29
3-8	3/4/4,3/3/4	3/6/4/7	3.60	5.00	4.00	5.00	0.55	1.83
3-12	6/4/4/4/6	5/7/6/7	4.80	6.25	4.00	6.50	1.10	0.96
3-13	6/5/8/5,4/6	5/3/7/5	6.00	5.00	6.00	5.00	1.22	1.63
4-1	2/2/5/2/2,1	1/2/3/2	2.60	2.00	2.00	2.00	1.34	0.82
4-2	1/1/1/5/2	3/4/4/3	2.00	3.50	1.00	3.50	1.73	0.58

Table 20: MS-1 and LNM CHR data (cont.)

Conf.	CHR MS-1	CHR LNM	Mean MS-1	Mean LNM	Median MS-1	Median LNM	Std dev MS-1	Std dev LNM
5-1	3/1/2/4/4	3/4/2/5	2.80	3.50	3.00	3.50	1.30	1.29
5-9	7/3/7/6/6	4/6/6/7	5.80	5.75	6.00	6.00	1.64	1.26
5-10	6/6/7/5/6,5	7/8/67	6.00	7.00	6.00	7.00	0.71	0.82
5-11	5/3,2/4/6/5	3/6/5/5	4.60	4.75	5.00	5.00	1.14	1.26

Figure 38 shows the median CH ratings of the 18 configurations of MS-1 and LNM. In general, the ratings had good correlation for both simulators with the exception of the configurations 4-2 and 3-12. Again, the difference in CH ratings between two simulators could come from the pilot variability or the visual displays of the two systems. More study about the differences between two simulators should be investigated in order to determine the causes.

Figure 39 shows the mean CH ratings of the 18 configurations of MS-1 and LNM. In general, the ratings had good correlation for both simulators. The mean CH ratings showed a little better correlation than the median ratings.

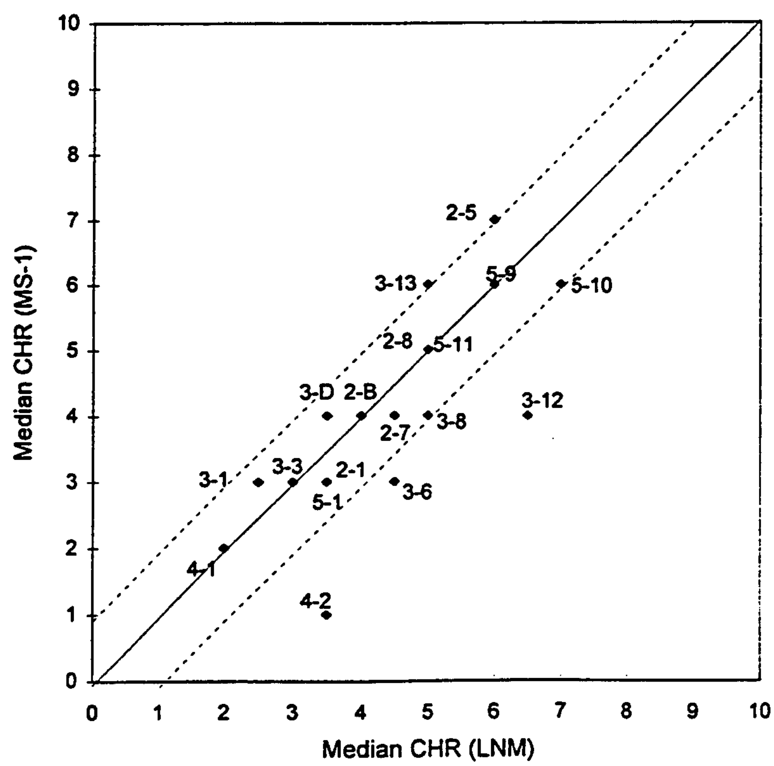


Fig. 38 MS-1 vs. LNM in Median CHR

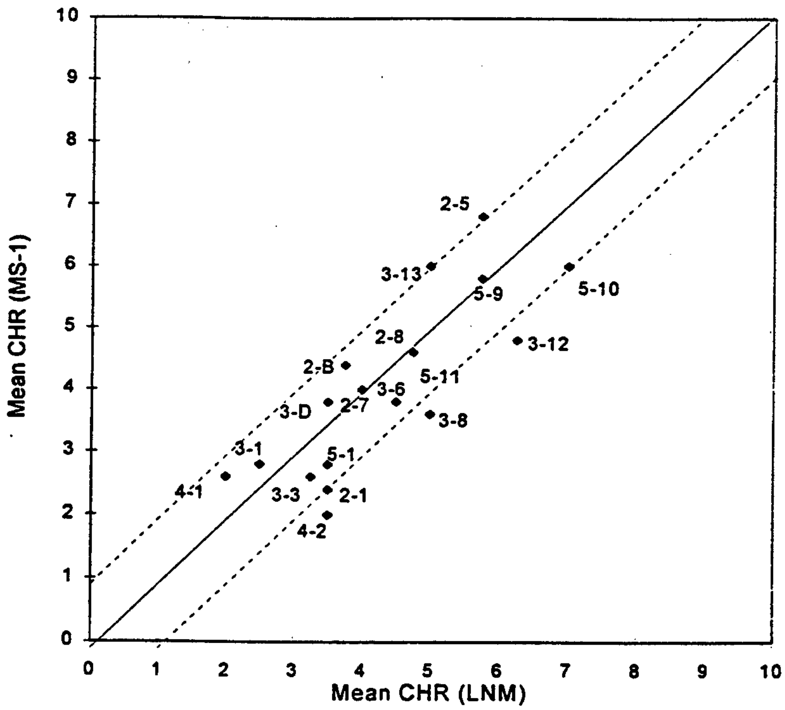


Fig. 39 MS-1vs. LNM in mean CHR

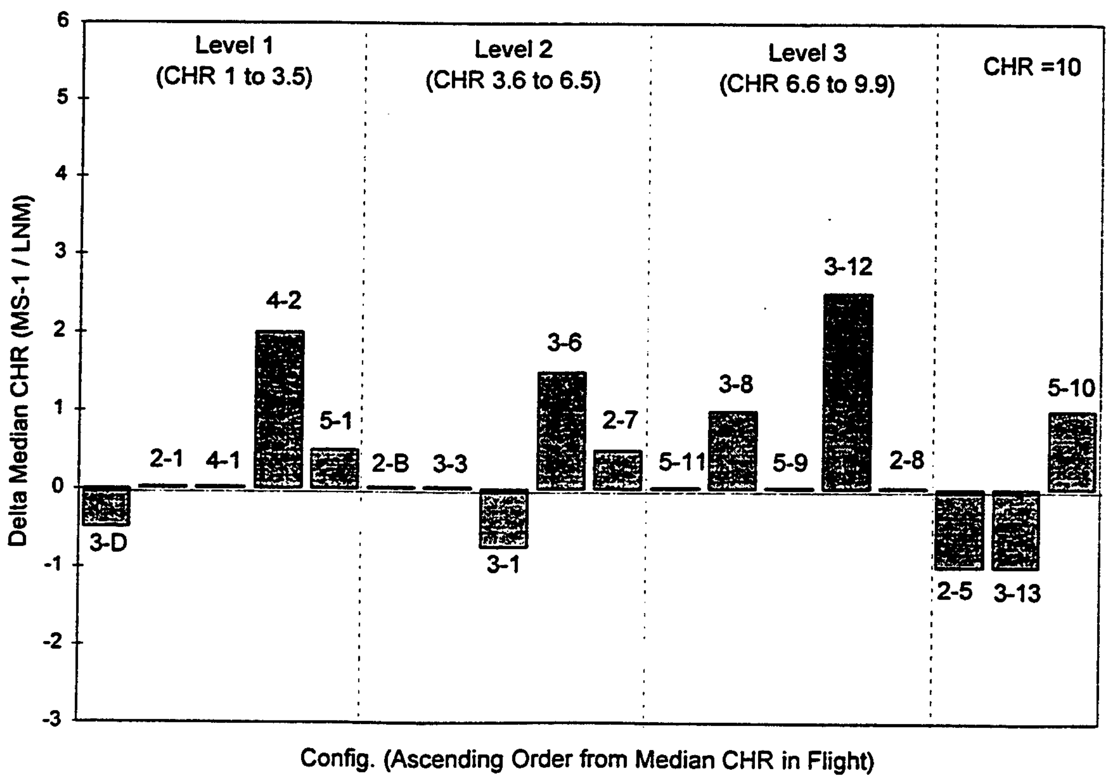


Fig. 40 MS-1/LNM in Median CHR Differences

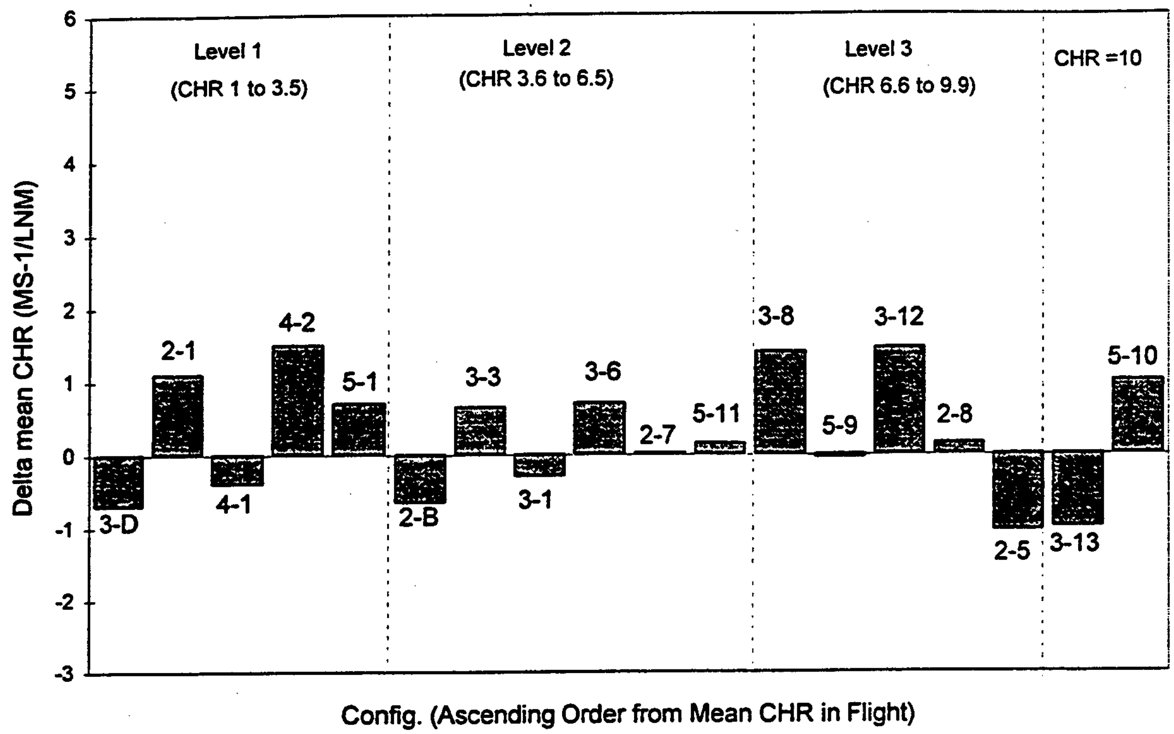


Fig. 41 MS-1/LNM in Mean CHR Differences

Fig. 40 and 41 show the differences (delta) between the two simulators in terms of mean and median CH ratings. A positive delta indicates higher ratings in LNM than in MS-1. Configurations are ordered from best to worst based on median and mean CHR from flight. The vertical dashed lines separate the data into regions roughly equivalent to flying qualities levels.

5.3 Phase I Results

As expected, evaluation of PIO tendencies in the simulator did not match the findings of flight test. However, the simulations did show the same trends as seen in flight. In general the best configurations in flight were also the best configurations in ground simulation; however, they were slightly better in flight than on the simulators. Mediocre configurations in flight were not always mediocre configurations in ground simulation. Worse configurations in flight were also worse configurations in the simulator; but they were not as bad in ground simulation as they were in flight. In other words, the configurations rated as "non PIO" in ground simulation (PIOR $\leq$ 2), were also "non PIO" configurations in flight. The configurations rated as "PIO" configurations (PIOR=4 or greater) in ground simulation were also "PIO" configurations in flight. The flight results cannot be predicted for the configurations which were rated from 2 to 4 in simulation PIO ratings. The ratings of these configurations in flight were from 1 to 4.5 in PIOR. Data showed not much difference in pilot ratings among the three simulators without the external disturbances. However, there was a question about the motion gain which was used

during the Phase I evaluation in LAMARS. Further investigation concerning the motion gains for LAMARS will be done at a later date.

During the Phase I testing, it appears that the pilots changed their behavior on the simulators. In other words, the pilots did not fly the simulators in the same way as the real airplane. They tended to fly the landing task as an open-loop task on the simulators. One possible reason was that there was no risk involved in the ground simulations. Another possible reason for that may be the poor visual cues in ground simulation. Consequently there were fewer PIOs encountered in the ground simulators, and even when they did occur the pilots sometimes did not even notice them. Fig. 42 shows a configuration which was PIO in flight. For the same configuration, a pilot got out of PIO in the ground simulation by neutralizing his stick input as shown in the plot. Unfortunately, the pilot did not recognize the oscillation and rated the configuration in CHR of 3 and in PIOR of 1.

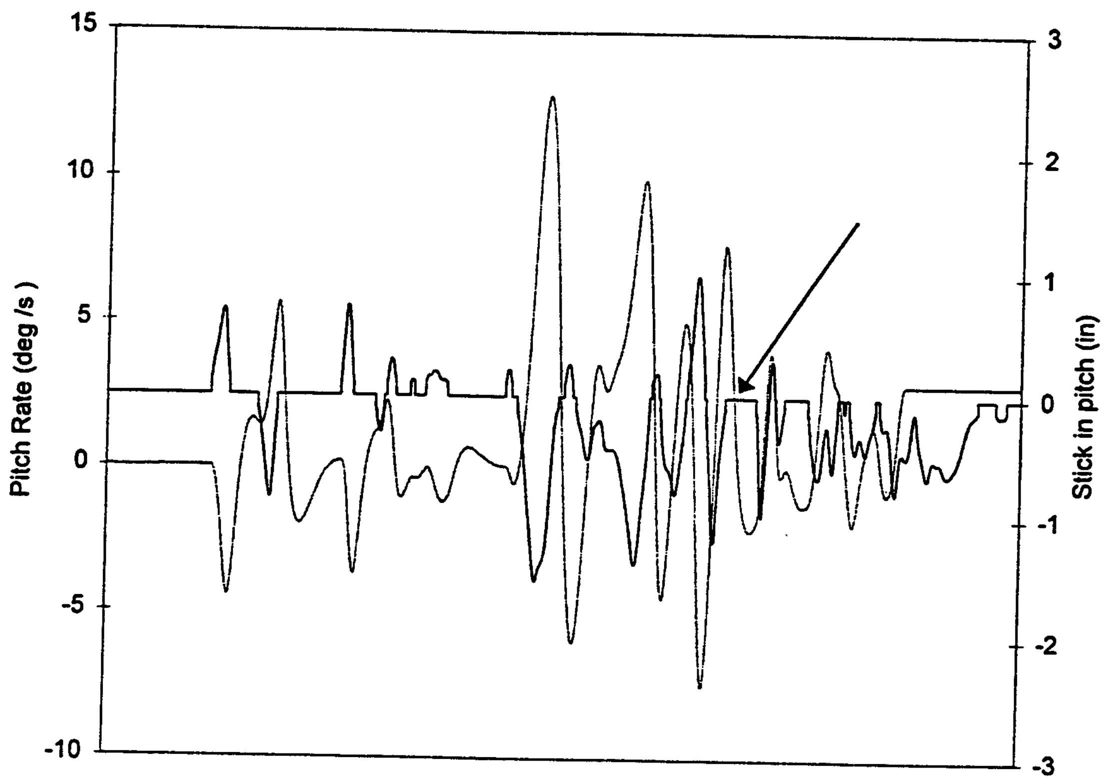


Fig. 42 Time History of a Configuration in MS-1

6. PHASE II SIMULATION EVALUATION

In Phase I, the ground-based simulation duplicated the in-flight simulation in accordance with best engineering practice. The ground simulation data showed similar trends as in flight. However, they did not match the flight test results. Therefore, Phase II of HAVE PIO program was to modify the ground-based simulation to better match or predict the flight results. The intent of the modifications was to increase the pilots' gain by making the task more difficult for them to fly. The modifications were expected to degrade the handling qualities of the bad configurations without affecting the handling qualities of the good configurations. Several changes were made to the simulation. These changes included adding gates, time delays, stick gains, and winds, gusts and turbulence. The performance criteria were kept the same as in Phase I. Due to the numerous changes to the simulation, one good (4-1) and one bad (5-10) of the 18 configurations were chosen for Phase II testing. The flying quality levels of the two configurations were based on flight test data. Phase II was conducted on MS-1 in Mar 96 with four pilots.

6.1 Simulation Modifications

6.1.1 Adding Gates

Fig. 43 shows the runway configuration during the Phase II simulation. Gates were added to the simulation to increase the pilots' workload and to improve visual cues. The purpose of adding gates at the offset and at the final approach locations was to emphasize the change from a lateral task to a longitudinal task and to increase the task difficulty and the pilots' gain. While pilots try to accomplish the task, under some high workload situations, they may trigger PIOs for the PIO prone configurations. Increasing the lateral offset distance and shortening the distance between the two gates made the task harder for the pilots to fly. Pilots were required to fly through the first gate before making the offset corrections and were also required to fly through the second gate before lining up with the centerline of the runway and attempting to land in the desired touchdown area. The gate was formed by two 210 foot vertical pylons. The base of each pylon was 20 feet. Each pylon was made of three color sections; purple, white and yellow. Each section is 70 feet long. The first gate was 150 feet wide. It was centered on the lateral offset positions, at 50 feet AGL. Initially the first gate was positioned 3500 feet from the touchdown point. The location of the first gate was varied. The second gate was fixed and was 75 feet wide. The bottom of the gate was placed at 5 feet AGL. The middle of the first section of the pylon of the first gate was on a glide-slope. The first gate was positioned 1100 feet from the touchdown point. To improve pilot visual cues during the touchdown, two pairs of horizontal pylons were added on both sides of the runway, at 40 feet before and after the desired touchdown point. This helped the pilots to reduce their touchdown dispersions. Another set of pylons was placed vertically at the touchdown point, on either side of the runway. These vertical pylons helped the pilots to improve their estimate of sink rate during the touchdown. The large black oval shape on the runway was the tire mark which helped the pilots to determine the location of the desired touchdown point. Three different offset locations of the gates; 150'/2400', 150'/1500'and 300'/2400'were evaluated on MS-1. The 150'/2400' represents the lateral offset distance from

the centerline of the gate to the center of the runway, and the longitudinal distance between two gates.

6.1.2 Time Delays

Two and three hundred milliseconds of pure time delays were added into the simulation model to artificially compensate for the pilots apparent increased tolerance to phase lag in the simulator. Under a high gain task, the pilots may get into PIOs for the PIO prone configurations due to phase lag problems.

6.1.3 Stick Gains

In flight, a nominal stick gain was set by having one pilot fly several different configurations until he was satisfied with the gain of the stick. Increasing the stick gains would make the pilots feel the configurations were a lot more sensitive than what they really are. The expectation was that the pilots would be likely to get into PIOs for the PIO prone configurations. Three levels of stick gain that were evaluated in the simulation were: two, two and a half, and three times the base line configuration.

6.1.4 Winds/Gusts/Turbulence

A wind/gust/turbulence model was implemented in the simulation. This was done to increase the task difficulty and pilots' workload. Twenty five and 40 knots steady quarterly wind (45 degree heading) with randomly mild to medium turbulence, with medium to heavy discrete gust, and with the gates set at 150'/2400', were evaluated on the simulator. A random left or right discrete gust occurred at the first gate; the offset correction. The random up or down discrete gust occurred at the second gate and approximately 40 feet AGL, and lasted for 5 seconds. The discrete gust on a final should upset the pilot's touchdown solution and force him back into the loop at high gain.

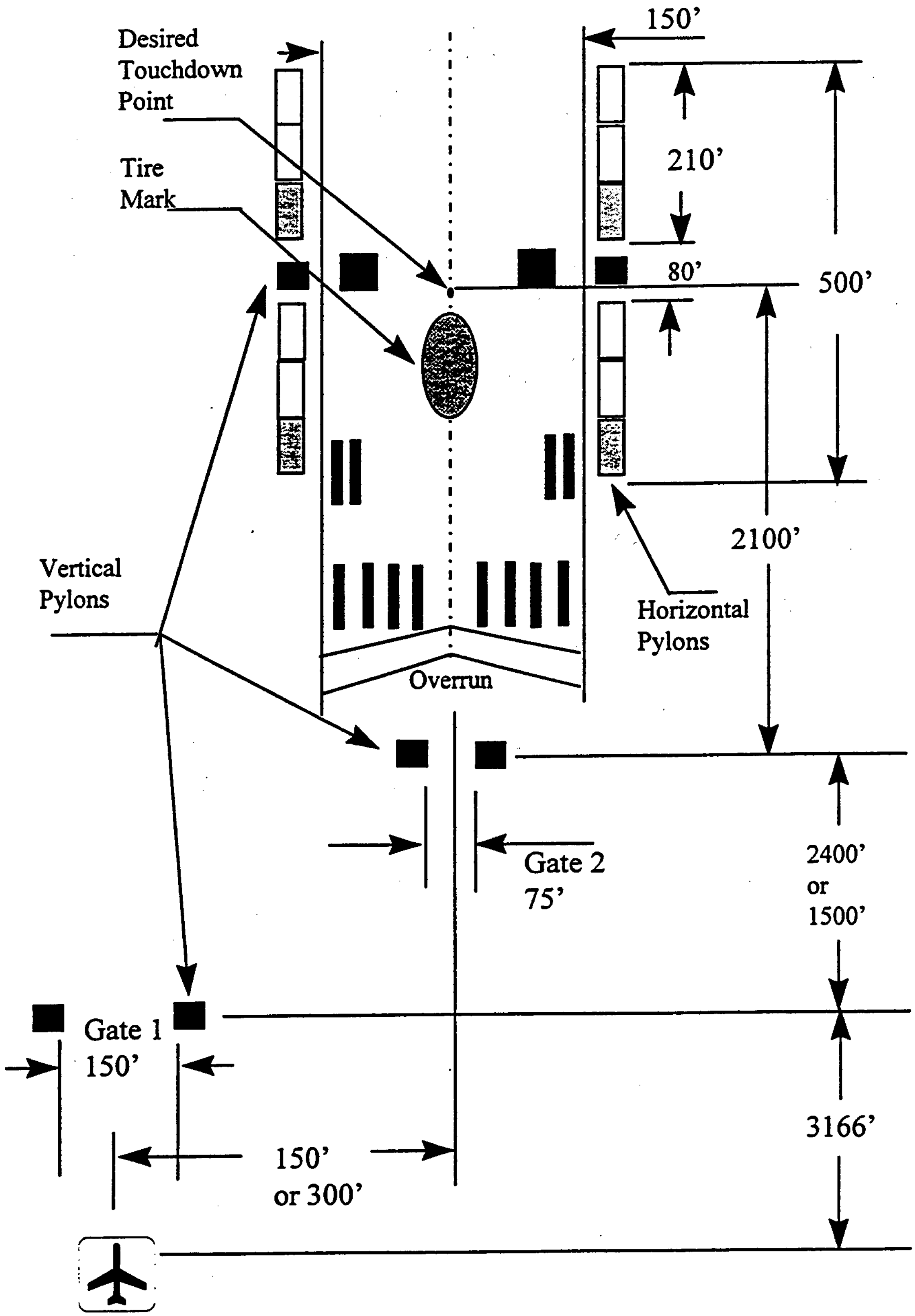


Fig. 43 Phase II Runway Configuration in Ground-Based Simulation (not to scale)

6.2 Piloted Evaluation

In Phase II, the landing task was again the same as in the HAVE PIO flight test program [6,7]. Prior to the pilot evaluation, a "corruptible" pilot checked out the simulation to make sure the simulation outputs met the engineering expectations. Engineers pre-briefed the pilots prior to their evaluations. Topics of pre-briefing were the tasks, the performance criteria, the runway configurations, Cooper-Harper and PIO rating scales. Prior to taking evaluation data, each pilot was given about 20 minutes for the cockpit familiarization. The purposes of the familiarization were: 1) to let the pilots check out the simulation for any errors which engineers missed, and 2) to let the pilots have the opportunity to see the different characteristics of the configurations due to the changes. The trial configurations during the familiarization were not in the test matrix. During the familiarization, the performance data (touchdown dispersions, sink rates, and speeds) were fed back to the pilots. Feeding back these performance data to the pilots during the familiarization would help the pilots to calibrate where they landed in relation to the touchdown point, and what their sink rates were. These data were not fed back to the pilots during the real evaluation. A baseline configuration in the Phase II simulation was defined as having no wind/gust/turbulence, nominal stick gain, no time delays, and no gates. To avoid any influences from the previous changes, the pilots flew the baseline configuration prior to a change. No combination of the changes was tried on the simulator.

Pilots used the long-look technique of Reference [10] for their evaluations. Each configuration was flown a minimum of three times before giving a rating. The three landings consisted of a straight-in approach, a left offset approach, and a right offset approach. Initial conditions were: approach speed of 135 KIAS, glide-slope of 2.5 degrees and an altitude of 248 feet AGL. Lateral offsets were varied for each set-up. Pilots maintained glide slope and heading while flying the offsets by using the first gate and the runway as reference points. As mentioned earlier, pilots were required to fly through the first gate, then made an offset correction to the centerline of the runway by going through the second gate and attempted to land in the desired area. Pilots were given the freedom to rerun any approaches until they were confident enough to give a rating. The Phase I performance criteria were used in Phase II. Pilots had to be fully satisfied before rating the configuration. Pilots were encouraged to give their comments during and after each run. That was helpful to the engineers in terms of data analysis.

6.3 Data Analysis

The primary metrics shown here for quantification are the Cooper-Harper and PIO Ratings. The ratings were validated with the pilot comments and performance. The elimination of the pilot ratings that conflicted with pilot comments and performance, had very little effect on the trends of the data. Therefore the author chose to use the raw data for the analysis. Tables 21-24 show the ratings of the configurations 4-1 and 5-10 against the changes. The first column of the table shows the changes to the simulation. These changes were three settings of the gates, two levels of wind, gusts and turbulence, two levels of time delay and three settings of the stick gains. The second column and thereafter show the pilot ratings in PIO or CH scales, the mean, median and standard deviation values for the configurations. Each pilot rating is separated by a slash.

Configuration 5-10 is a sluggish configuration with lots of phase lag. When 300 msec was added to the model, one pilot rated the configuration 10 in CHR and 6 in PIOR. Another pilot flew this configuration and rated it 4 in CHR and 2 in PIOR. It turned out that the pilot who gave high ratings for the configuration had lots of experience in a fighter airplane and flew the configuration at a high gain. The other pilot who gave low ratings for the configuration had lots of experience in a transport airplane and flew the configuration at a low gain. The low gain pilots tended to tolerate the sluggish configurations (lots of phase lag) better than the high gain pilots.

Table 21: PIOR of Configuration 4-1

Changes	PIOR	Mean	Median	Std. Dev.
Baseline	1/1/1/2	1.25	1.00	0.50
150'/2400'	1/3/1/1	1.50	1.00	1.00
150'/1500'	1/1/3/3	2.00	2.00	1.15
300'/1500'	1/3.5/1/1	1.63	1.00	1.25
25 kts	1/1/2/1	1.25	1.00	0.50
40 kts	1/2/2/1	1.50	1.50	0.58
200msec	1/2/1/1	1.25	1.00	0.50
300msec	2/4/2/1	2.25	2.00	1.26
x2	2/2/4/4	3.00	3.00	1.15
x2.5	4/1/4/1	2.50	2.50	1.50
x3	3/3/4/3	3.25	3.00	0.50

Table 22: CHR of Configuration 4-1

Changes	CHR	Mean	Median	Std. Dev.
Baseline	2/3/2/4	2.75	2.50	0.96
150'/2400'	2/5/2/1	2.50	2.00	1.73
150'/1500'	3/5/4/3	3.75	3.50	0.96
300'/1500'	5/3/6/3	4.25	4.00	1.50
25 kts	6/4/3/5	4.50	4.50	1.29
40 kts	6/5/7/5	5.75	5.50	0.96
200msec	5/3/3/3	3.50	3.00	1.00
300msec	5/4/3/3	3.75	3.50	0.96
x2	3/4.5/5/6	4.63	4.75	1.25
x2.5	5/5/4/3	4.25	4.50	0.96
x3	5/5/8/6	6.00	5.50	1.41

Table 23: PIOR of Configuration 5-10

Changes.	PIOR	Mean	Median	Std. Dev.
Baseline	4/4/2/4	3.50	4.00	1.00
150'/2400'	2/4/4/4	3.50	4.00	1.00
150'/1500'	3/4/2/4	3.25	3.50	0.96
300'/1500'	1/4/1/1	1.75	1	1.50
25 kts	3/2/4/4	3.25	3.50	0.96
40 kts	4/4/4/3	3.75	4.00	0.50
200msec	4/4/2/3	3.25	3.50	0.96
300msec	6/4/3/3	4.00	3.50	1.41
x2	5/4/3/3	3.75	3.50	0.96
x2.5	5/5/4/4	4.50	4.50	0.58
x3	6/5/5/5	5.25	5.00	0.50

Table 24: CHR of Configuration 5-10

Changes	CHR	Mean	Median	Std. Dev.
Baseline	6/6/3/7	5.50	6.00	1.73
150'/2400'	6/7/6/7	6.50	6.50	0.58
150'/1500'	6/7/4/5/6	5.60	6.00	1.14
300'/1500'	7/8/7/6	7.00	7.00	0.82
25 kts	7/6.5/8/7	7.13	7.00	0.63
40 kts	9/9/7/7	8.00	8.00	1.15
200msec	6/5/4/6	5.25	5.50	0.96
300msec	10/9/5/6	7.50	7.50	2.38
x2	8/5/4/6	5.75	5.50	1.71
x2.5	9/10/8/7	8.50	8.50	1.29
x3	10/10/10/8	9.50	10.0	1.00

The difference in mean and median values of the two configurations was small. Therefore the author chose to use the mean data for the analysis. Phase II data analysis shown here is representative of the effects of the changes to the simulation in terms of pilot ratings. In general, the pilot ratings correlated well with pilot performance, even though pilots had some visual cue limitations on judging their landing dispersions during the simulation. The vertical and horizontal pylons on two sides of the runway, tire mark, stripes on the runway, earth/sky line,

the bouncing of the flight path marker in the Head-Up Display (HUD), and the audible "squeak" when the pilot touched down were all contributors to the pilots task of determining where and when they landed. The vertical and horizontal pylons also contributed to the pilots' ability to determine their sink rates.

Three hundred and fifty data runs were collected in Phase II simulation. Fig. 44 shows the average Cooper-Harper Rating of configurations 5-10 and 4-1 versus the changes on MS-1. The horizontal axis of the plot shows the baseline configuration and four different categories of change to the simulation. The left axis of the plot is the average CHR scale. No trend in task difficulty is implied by the order. Fig. 44 also shows the average simulation CHR of configuration 4-1 matched very well with the flight test data in a baseline configuration. However, the average simulation CHR of configuration 5-10 was noticeably different from the flight test ratings in a baseline configuration. The success of the changes shown is judged by how well they move the ratings of configuration 5-10 toward the flight test value without changing the ratings on configuration 4-1.

As expected, when levels of the task difficulty are increased, the pilot workloads are also increased for both configurations. Adding the gates to the baseline configuration at 150'/2400' and 150'/1500' had little effect on the average CHRs of both configurations. However, there were moderate effects on the CHRs of both configurations by reducing the distance between the two gates and increasing the lateral offset distance. The data showed moderate effects on the average CHRs of both configurations with the winds, gusts, and turbulence at 25 kts and significant effects on the average CHRs of both configurations at 40 kts. Adding time delays to the simulation, data showed little effect on the average CHRs of both configurations. However, there were significant effects on the average CHR of the configuration 5-10 with 300 milliseconds time delay. Increasing the stick gain to two times from the baseline configuration had little effect on the average CHR of the configuration 5-10, and moderate effects on the average CHR of the configuration 4-1. Increasing the stick gain to two and half times from the baseline configuration had moderate effects on the average CHR of the configuration 4-1. However, it had significant effects on the average CHR of the configuration 5-10. Increasing the stick gain to three times from the baseline configuration had very significant effects on the average CHRs of both configurations.

The best explanation for the results in Phase II is that this approach does not distinguish between good and bad configurations. In other words, our original concepts were wrong.

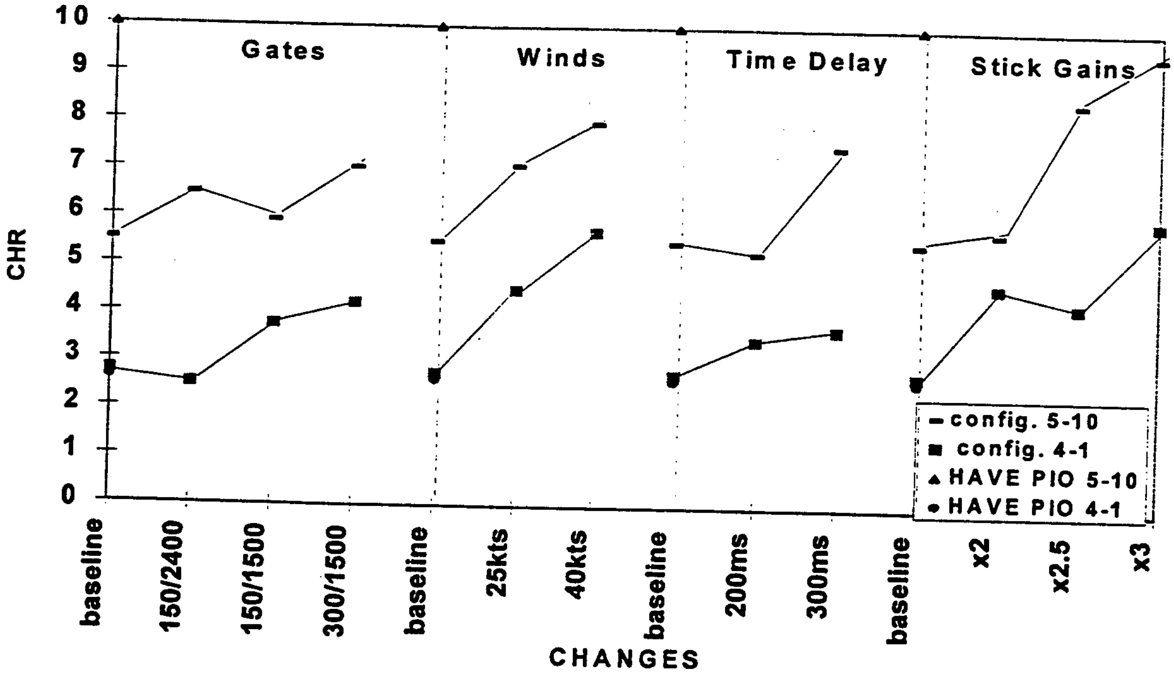


Fig. 44 Average CHR for Configurations
5-10 and 4-1 vs. Changes

Among the four changes to the simulation, the stick gain at three times from the baseline configuration was the only change that the average CHR of the configuration 5-10 came close to the HAVE PIO flight test data. However, the average CHR of the configuration 4-1 did not match the HAVE PIO flight test data with this change. Therefore, these changes were not considered to be good.

Fig. 45 shows the average PIO ratings for configurations 5-10 and 4-1 versus the changes to the simulation.

As expected, when levels of the task difficulty were increased, the average PIO ratings were also increased for both configurations. Increasing the task difficulty by reducing the distance between two gates or increasing the lateral offset had little effect on the average PIO ratings of both configurations. Data also showed little effect on the average PIO ratings of both configurations with increasing the magnitude of the winds/gusts/turbulence. Adding 200 milliseconds time delay to the simulation did not affect the average PIO ratings of both configurations. However, adding 300 milliseconds time delay to the simulation had a moderate effect on the average PIO ratings of both configurations. Increasing the stick gains had a significant effect on the average PIO ratings of both configurations with the exception of two times of the stick gain where the change did not affect the average PIO rating of the configuration 5-10. Among the four changes to the simulation, the stick gain at three times from the baseline configuration was the only change that the average PIO rating of the configuration

5-10 matched the HAVE PIO flight test data. However, the average PIO rating of the configuration 4-1 did not match the HAVE PIO flight test data with this change.

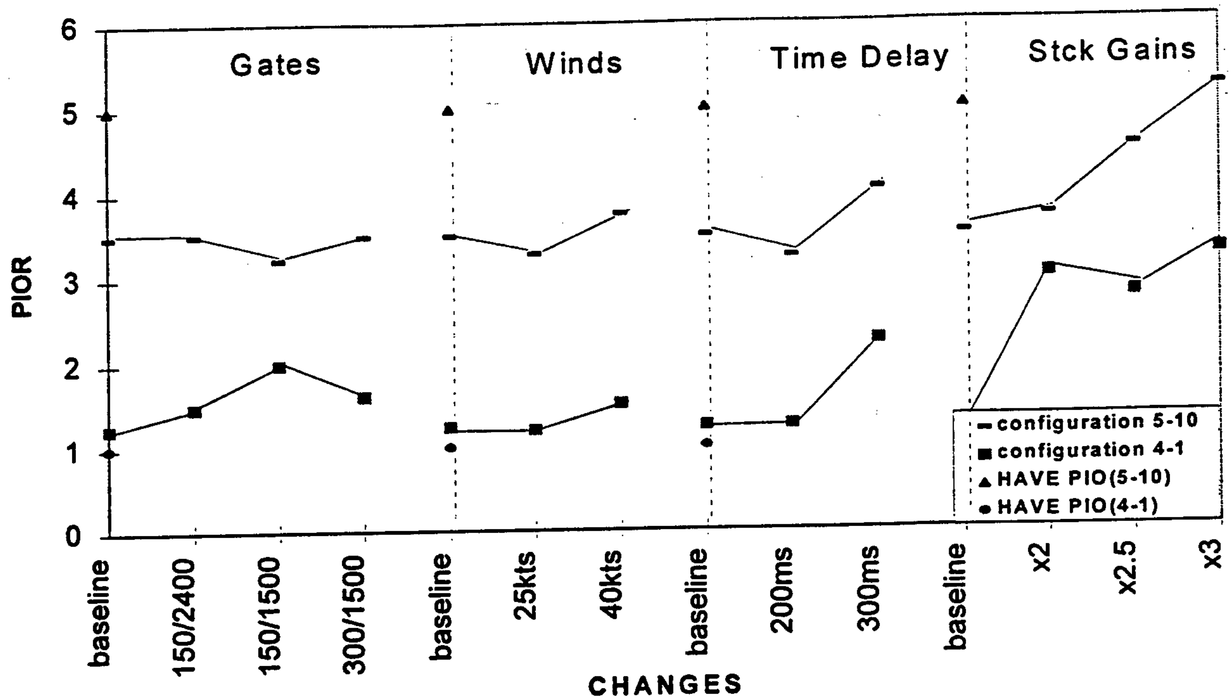


Fig. 45 Average PIO Ratings for Configurations 5-10 and 4-1 vs. Changes

Fig. 46 shows the average CHR and the individual CHR of the pilots due to the changes in the simulation. Four symbols in the plot represented the CHR of the pilots. Again the dashed symbols represented the average CHR of configuration 4-1 due to the changes. As it was mentioned before when levels of the task difficulty were increased, the pilot ratings were also increased with some exceptions. Pilot B somehow felt that it was easier to fly the gate setting at 300'/1500' than at 150'/1500'. While increasing the task difficulty by increasing the lateral offset distance of the gate from 150'to 300', pilot B decreased his CH rating from 5 to 3. Another inconsistency in the pilot ratings was in the stick gain changes. While increasing the level of task difficulty by increasing the stick gain from 2 times to 3 times of the nominal stick gain, pilots C and D decreased their CH ratings.

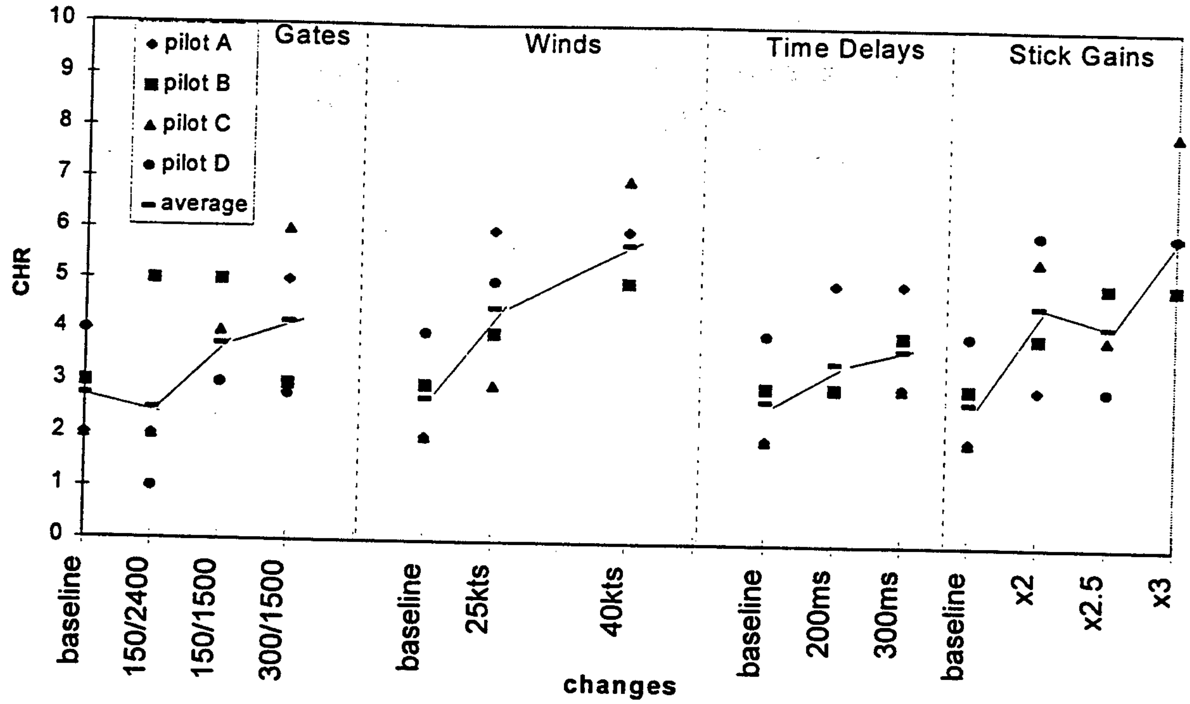


Fig. 46 CHR of Configuration 4-1 vs. Changes

Fig. 47 shows the average and individual PIO ratings of the pilots for configuration 4-1 due to the changes. Again the horizontal axis of the plot shows the baseline and four different changes to the simulation. The changes were: the gates, the winds, gust and turbulence, the time delays, and the stick gains. The vertical axis of the plot is the PIO ratings. There was some inconsistency in the pilot ratings. Increasing the level of task difficulty by shortening the distance between two gates from 2400' to 1500', pilot B decreased his PIO rating from 3 to 1. Pilots C and D decreased their PIO ratings from 3 to 1 while a level of the task difficulty was increased by reducing the lateral distance between two gates from 150' to 300'. Increasing the stick gains from 2 to 2.5 times the nominal stick gain was expected to increase the pilot ratings. However, the PIO rating of pilot C was decreased.

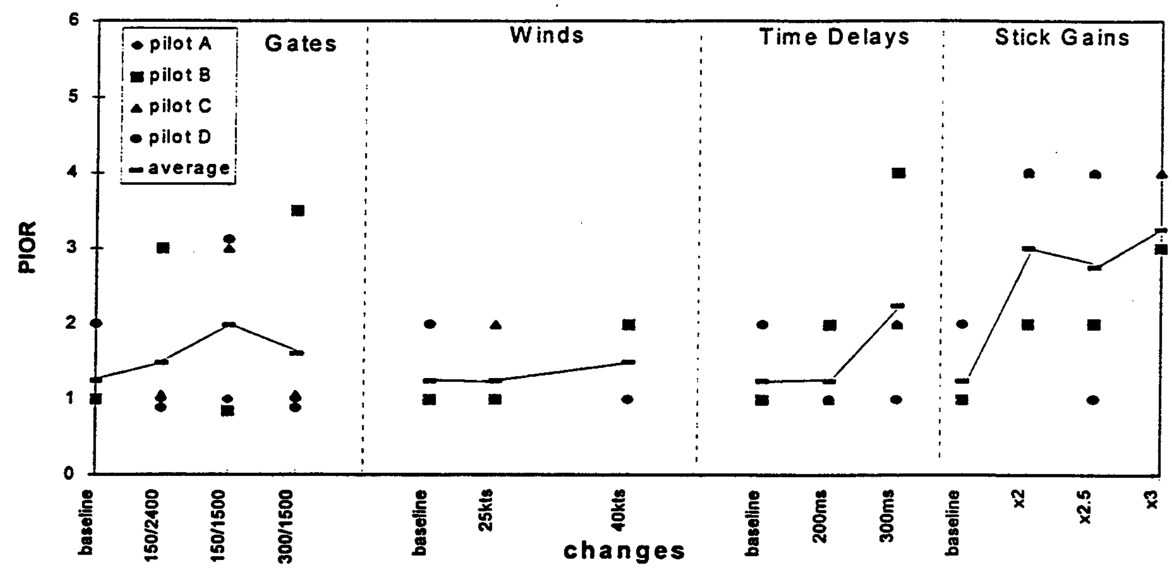


Fig. 47 PIOR of Configuration 4-1vs. Changes

Fig. 48 shows the average and individual CH ratings of the pilots due to the changes in the simulation. The plot was labeled the same way as the previous plot. There was a good correlation between the pilot ratings and the changes to the simulation.

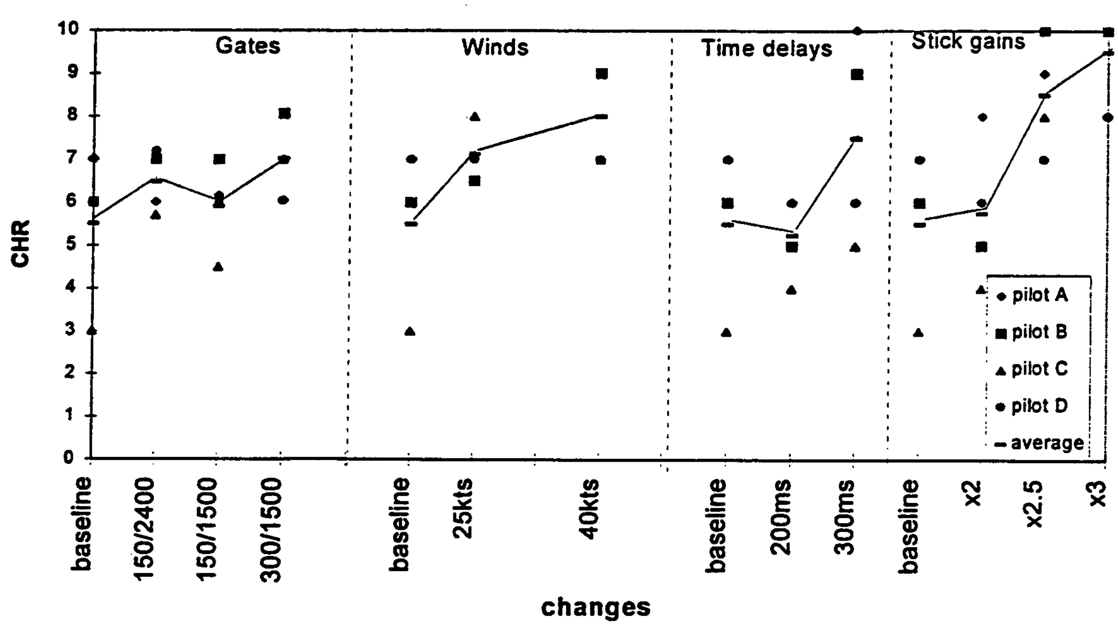


Fig. 48 CHR of Configuration 5-10 vs. Changes

Fig. 49 shows the average and individual PIO ratings of the pilots for the configuration 5-10 due to the changes in the simulation. The plot was labeled the same way as the previous plot. In general, when the level of task difficulty is increased, the pilot ratings are also increased. However, in this plot pilot C decreased his PIO ratings from 4 to 2 when the longitudinal distance between two gates was reduced from 2400' to 1500'. Shortening the distance between the two gates made the task harder for pilots to fly.

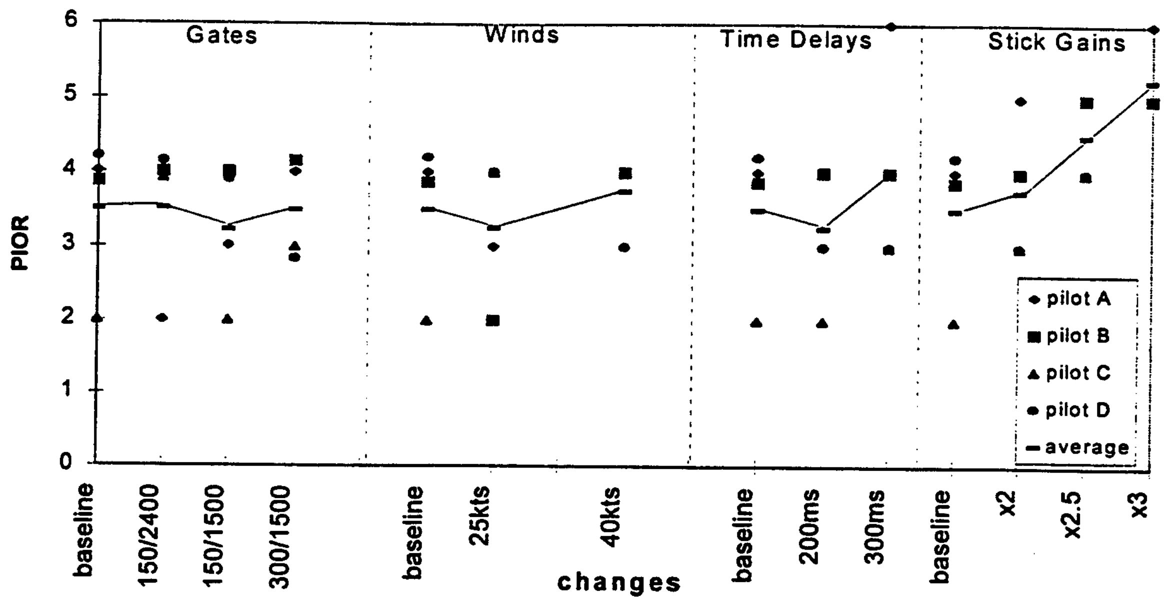


Fig. 49 PIOR of Configuration 5-10 vs. Changes

6.4 Phase II Results

The results of the Phase II testing did not match the authors' expectation, nor the flight test. In order to be considered a good change, the change must only degrade the PIO susceptibility of the bad configuration (5-10), and keep the susceptibility of the good configuration (4-1) the same as the baseline. The data showed none of the changes were completely effective because they did not satisfy the above condition.

As expected, tightening the tasks by adding gates, more time delays in the model, stick gains and winds, gusts and turbulence on the ground based simulators brought the pilot's C-H and PIO ratings closer to the flight test ratings for the bad configuration (5-10). However, the modifications also degraded the C-H and PIO ratings of the good configuration (4-1). It is very difficult to increase the pilot gains by tightening the landing task without degrading the handling qualities of the good configuration on the ground-based simulator.

7. GENERAL OBSERVATIONS AND CONCLUSIONS

In Phase I, duplicating the flight process of PIO testing in the ground-based simulators did not closely match the flight results. However, the ground simulation did give the same trends as in flight. In Phase II, as expected, when the levels of the task difficulty were increased, the pilot ratings were also increased for both PIO and non-PIO configurations in the ground simulation. Pilots tended to behave much different on the simulators than in flight because the cues are different. In flight, the pilots have real motion and visual displays, and are at high risk versus limited motions, artificial visual cues, and no risk in ground-based simulation. It was very difficult to increase the pilot gains without degrading the flying qualities of the configurations by tightening the landing task on the ground simulators. Some pilots had a tendency to back out of the task. Looking for PIOs on ground-based simulators may require some pilot skills and some very specific tasks such as target tracking, precision offset landing, air refueling or close formation where the pilots cannot back out.

In the time history analysis, pilots sometimes overpredicted the PIO ratings for the sensitive non-PIO configurations and underpredicted for PIO configurations. Overpredictions of the non-PIO configurations in the ground simulation could come from the stick sensitivity rather than the configurations. Underpredictions of the PIO prone configurations could come from poor visual cues, a lack of real motion cues, and some other factors, which have not been studied yet in the ground simulators. Tasks and the test subjects are important in PIO testing, along with the ground rules. The landing tasks may not be a high gain task in the ground simulation because there is no risk involvement. As shown earlier, sometimes pilots missed detecting PIO with two or three cycles at 5 deg/s pitch rate in ground simulation. Again, this could be the poor visual cues on the HUD or something else, which has not been yet studied.

To have a ground-based simulation of a landing task match flight test results, it may require some interpretations about the PIO and CH rating scales in ground simulation. The pilots measure the level of the aircraft safety much different in flight than in the ground simulation. In flight when the safety pilot feels the aircraft at risk, he will take control away from the project pilot. This is at least 8 or 9 or even 10 in CHR and 5 or 6 in PIOR. In the ground simulation, the pilots may face the same situation, but he manages to land instead of going around. Therefore, the pilot will give 6 or 7 in CHR and 4 in PIOR. Both scales seemed to work well for the good configurations (PIOR <2 and CHR<4) in flight and the ground simulation. However, they may not work well for bad configurations in ground-based simulation.

Figure 50 shows a pilot activity against the pitch rate in a time history plot during an offset landing task. The left vertical axis of the plot is a pitch rate response of the aircraft in degrees per seconds. The right vertical axis is stick input from the pilot in inches. The horizontal axis is time in second. In a first part of the run, the pilot sampled the configuration by applying doublets at large amplitude in pitch. After sampling the configuration, he knew that the configuration was susceptible to PIO; therefore; he reduced his gain to fly the rest of the task. For this run, the pilot did not see any PIO during the actual task, but he encountered a PIO during his sampling period. Pilots must fly at high gain for a high gain task in order to see PIO. Otherwise, they may not see PIO at all. If they do, the level of PIO won't be as severe as when

they fly the configurations at high gains. In this test, a majority of the pilots used the results during the sampling period as a primary factor to rate the configurations unless they saw different dynamics in the configurations during touchdown.

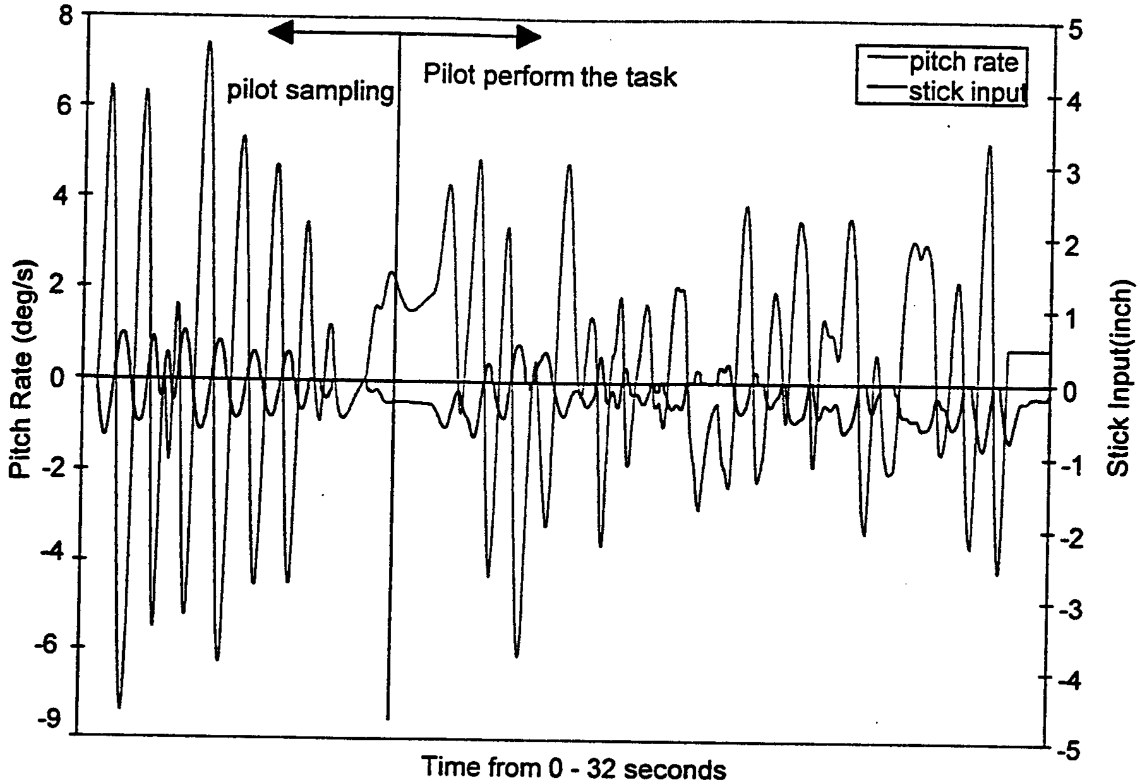


Fig. 50 Time History of a Configuration from LAMARS

As stated earlier, the ground-based simulators can duplicate the flight test results. However, the ground-based simulators have not been successful at detecting PIO problems prior to flight test.

8. FUTURE PLANS

There will be an addendum to this report in March 99. The addendum will have the following results: 1) The time history analysis of flight and simulation data of HAVE PIO database. 2) Complete analysis results of FIDO. FIDO [15] currently catches PIOs about seventy five percent, and ten percent chance of being wrong when it trips. 3) The analysis of Power Spectral Density (PSD) of pilot stick inputs. 4) The program summary along with lessons learned. There will a separate technical report for the comparison of flight and ground simulation in terms of nonlinear causes of PIO (HAVE LIMITS database), and will be a technical report of the procedures for PIO risk reduction.

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APPENDIX A

SELECTED FLIGHT PILOT COMMENT CARDS

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INFLIGHT PILOT COMMENT CARD

FLT NO.= 3	RUN NO.= 4	ω_{nSP} = 2.4	DATE: 17MAY86
CONFIGURATION NO.= 2-B		ξ_{SP} = 0.64	PILOT: A
GEARING = 0.170		FCS = 3.0(3.33)/(10.0)	IP: PARRAG

PIO RATING = 3	C-H RATING = 7	CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light to medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium response rate
- FINAL RESPONSE: Medium response rate
- PREDICTABILITY: Less than satisfactory
- PILOT COMPENSATION: Reduced gain required
- PIO TENDENCY: Yes

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Adequate (± 500 feet) 50 % of time
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: Reduced gain
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: Light turbulence on final
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Poor pitch control in flare. Low amplitude, medium frequency PIO made touchdown accuracy difficult.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 17 RUN NO.= 1 ω_{nSP} = 2.4 DATE: 29MAY86
CONFIGURATION NO.= 2-B ξ_{SP} = 0.64 PILOT: B
GEARING = 0.170 FCS = 3.0(3.33)/(10.0) IP: HARPER

PIO RATING = 2 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium to heavy, no factor
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Fast
- FINAL RESPONSE: Fast
- PREDICTABILITY: Good
- PILOT COMPENSATION: Medium
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: Medium
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: Head wind at 10 kt gusting to 18 kt
- TURBULENCE: Light
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Undesirable jerky motion during flare, but no factor in achieving desired performance.

- GOOD FEATURES: No PIO tendency noted, performs well except for flare.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 15	RUN NO.= 4	ω_{nSP} = 2.4	DATE: 29MAY86
CONFIGURATION NO.= 2-B		ζ_{SP} = 1.0	PILOT: C
GEARING = 0.170		FCS = 3.0(3.33)/(10.0)	IP: HARPER

PIO RATING = 1 | C-H RATING = 3 | CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS:
- FORCES: Medium forces
- PITCH SENSITIVITY: High

PITCH ATTITUDE CONTROL:
- INITIAL RESPONSE: Fast
- FINAL RESPONSE: Fast
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Small control stick deflections in flare
- PIO TENDENCY: None

TASK PERFORMANCE:
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High gain
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS:
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION:
- MAJOR PROBLEMS: None.
- GOOD FEATURES: Good flying qualities.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 10	RUN NO.= 4	ω_{nSP} = 2.4	DATE: 22MAY86
CONFIGURATION NO.= 2-B		ζ_{SP} = 0.64	PILOT: C
GEARING = 0.170		FCS = 3.0(3.33)/(10.0)	IP: HARPER

PIO RATING = 2 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Fast
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Medium compensation required to shape the inputs and lower gain.
- PIO TENDENCY: Slight

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired(± 5 kt)
- TOUCH DOWN POINT: Adequate (+ 500 feet) due to long flare
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Very high
- SPECIAL CONTROL: Compensation required to lower gain during flare
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: Small amplitude, high frequency oscillation tendency, did not affect task performance.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 6	RUN NO.= 3	ω_{nSP} = 2.4	DATE: 21MAY86
CONFIGURATION NO.= 2-1		ξ_{SP} = 0.64	PILOT: B
GEARING = 0.170		FCS = 1	IP: EASTER

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Quick
- FINAL RESPONSE: Quick
- PREDICTABILITY: Good
- PILOT COMPENSATION: Not required
- PIO TENDENCY: None

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: 70 degrees cross wind at 15 kt
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: None.

- GOOD FEATURES: Quick response. Corrections were quickly damped. Felt like normal flare except for quicker response.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 16	RUN NO.= 1	ω_{nSP} = 2.4	DATE: 29MAY86
CONFIGURATION NO.= 2-1		ξ_{SP} = 0.64	PILOT: A
GEARING = 0.170		FCS = 1	IP: EASTER

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium forces
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Medium to fast
- FINAL RESPONSE: Medium
- PREDICTABILITY: Excellent
- PILOT COMPENSATION: None
- PIO TENDENCY: None

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium to high gain
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS:

- GOOD FEATURES: Good flying qualities

INFLIGHT PILOT COMMENT CARD

FLT NO.= 15	RUN NO.= 3	ω_{nSP} = 2.4	DATE: 29MAY86
CONFIGURATION NO.= 2-1		ζ_{SP} = 0.64	PILOT: C
GEARING = 0.170		FCS = 1	IP: HARPER

PIO RATING = 1 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: None
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High gain
- SPECIAL CONTROL: A little lowered gain in flare
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: None.

- GOOD FEATURES: Good flying qualities.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 12	RUN NO.= 3	ω_{nSP} = 2.4	DATE: 27MAY86
CONFIGURATION NO.= 2-5		ξ_{SP} = 0.64	PILOT: A
GEARING = 0.250		FCS = 1.0/(1.0)	IP: HARPER

PIO RATING = 4 C-H RATING = 10 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium to heavy
- PITCH SENSITIVITY: Low to medium

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Sluggish
- FINAL RESPONSE: Slow to medium
- PREDICTABILITY: Unpredictable
- PILOT COMPENSATION: High gain shaping
- PIO TENDENCY: Low frequency PIO

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Adequate (± 500 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Dropped in
- AGGRESSIVENESS: High gain
- SPECIAL CONTROL: Lead compensation
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Low frequency, medium amplitude PIO in flare. High stick forces coupled with sluggish control led to quick out of phase PIO-not landable. Touchdowns occurred as PIO "bottomed out".

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 11 RUN NO.= 3	ω_{nSP} = 2.4		DATE: 27MAY86
CONFIGURATION NO.= 2-5	ζ_{SP} = 0.64		PILOT: C
GEARING = 0.250	FCS = 1.0/(1.0)		IP: EASTER

PIO RATING = 5 C-H RATING = 10 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium to heavy
- PITCH SENSITIVITY: Very low

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Very sluggish
- FINAL RESPONSE: Sluggish
- PREDICTABILITY: Very, very poor
- PILOT COMPENSATION: High
- PIO TENDENCY: High

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: No touch down
- RUNWAY ALIGNMENT: No touch down
- TOUCH DOWN SINK RATE: No touch down
- AGGRESSIVENESS: High
- SPECIAL CONTROL: Lowered gain to avoid oscillation
- REASON APP. ABANDON: Steady sustained oscillation on final. Divergent oscillation in flare

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Very slow frequency sustained oscillation on final approach, and divergent PIO in flare.
  Poor predictability and slow response in pitch.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 17	RUN NO.= 3	ω_{nSP} = 2.4	DATE: 29MAY86
CONFIGURATION NO.= 2-5		ξ_{SP} = 0.64	PILOT: B
GEARING = 0.250		FCS = 1.0/(1.0)	IP: HARPER

PIO RATING = 4 C-H RATING = 7 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium
- PITCH SENSITIVITY: Low

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Slow
- FINAL RESPONSE: Slow
- PREDICTABILITY: Poor
- PILOT COMPENSATION: High
- PIO TENDENCY: High

TASK PERFORMANCE :
- AIRSPEED CONTROL: Adequate(- 5 kt, +10 kt)
- TOUCH DOWN POINT: Long
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: High
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :
- WIND: 210 / 10 G 18 kt
- TURBULENCE: Light
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: Pilot out of phase. Low frequency wallowing motion. Very hard to control touch down point due to lag and overshoot. First approach divergent, next two were not divergent with considerable pilot compensation.
- GOOD FEATURES: Landed safely twice.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 17	RUN NO.= 2	ω_{nSP} = 2.4	DATE: 29MAY86
CONFIGURATION NO.= 2-7		ζ_{SP} = 0.64	PILOT: B
GEARING = 0.170		FCS = 144/[0.7, 12]	IP: HARPER

PIO RATING = 3 C-H RATING = 4 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Slow
- FINAL RESPONSE: Medium
- PREDICTABILITY: Good
- PILOT COMPENSATION: Medium
- PIO TENDENCY: Low

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: Medium
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: 210/10 G 18 kt
- TURBULENCE: Light
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: Sluggish, low frequency pitch response with moderate lag. Not really PIO but small overshoots due to slow lagging response. Desired performance attainable, but deficiencies warrant improvement.

- GOOD FEATURES: Undesirable motion can be stopped in 1 to 2 cycles with moderate pilot compensation.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 10	RUN NO.= 2	ω_{nSP} = 2.4	DATE: 22MAY86
CONFIGURATION NO.= 2-7		ζ_{SP} = 0.64	PILOT: C
GEARING = 0.170		FCS = 144/[0.7, 12]	IP: HARPER

PIO RATING = 2 C-H RATING = 4 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Low compensation required
- PIO TENDENCY: Slight

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Less than adequate due to long flare
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High
- SPECIAL CONTROL: Lower gain
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Small amplitude, medium frequency oscillation in flare.
- GOOD FEATURES: Pilot could still control the aircraft effectively.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 5	RUN NO.= 1	ω_{nSP} = 2.4	DATE: 21MAY86
CONFIGURATION NO.= 2-8		ζ_{SP} = 0.64	PILOT: C
GEARING = 0.170		FCS = 81/[0.7, 9]	IP: EASTER

PIO RATING = 4 C-H RATING = 8 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium response rate
- FINAL RESPONSE: Medium response rate
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Reduced gain required with PIO
- PIO TENDENCY: Medium

TASK PERFORMANCE :

- AIRSPEED CONTROL: Adequate (- 5 kt, +10 kt)
- TOUCH DOWN POINT: No touch down
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: No touch down
- AGGRESSIVENESS: Very high
- SPECIAL CONTROL: Lower the gain
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: PIO tendency. Freezing stick often necessary to stop PIOs. Medium frequency, low amplitude motion, not divergent.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 16	RUN NO.= 2	ω_{nSP} = 2.4	DATE: 29MAY86
CONFIGURATION NO.= 2-8		ζ_{SP} = 0.64	PILOT: A
GEARING = 0.170		FCS = 81/[0.7, 9]	IP: EASTER

PIO RATING = 4 C-H RATING = 10 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium to heavy forces
- PITCH SENSITIVITY: Low

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Sluggish
- FINAL RESPONSE: Sluggish
- PREDICTABILITY: Poor
- PILOT COMPENSATION: High compensation required
- PIO TENDENCY: Medium to high

TASK PERFORMANCE :

- AIRSPEED CONTROL: N/A
- TOUCH DOWN POINT: N/A
- RUNWAY ALIGNMENT: N/A
- TOUCH DOWN SINK RATE: N/A
- AGGRESSIVENESS: High gain
- SPECIAL CONTROL: High gain
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: PIO even in turbulence
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Aircraft motion lags control inputs. Any pitch inputs led to low frequency, medium amplitude PIO. PIO's up and away on downwind.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 14	RUN NO.= 4	ω_{nSP} = 4.1	DATE: 27MAY86
CONFIGURATION NO.= 3-D		ξ_{SP} = 1.0	PILOT: C
GEARING = 0.500		FCS = 0.5(20.0)/(10.0)	IP: EASTER

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium
- PITCH SENSITIVITY: Medium to high

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Fast
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: None
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS:

- GOOD FEATURES: Aircraft flew well both final and flare. Aircraft responds well to pilot

INFLIGHT PILOT COMMENT CARD

FLT NO.= 7 RUN NO.= 4 ω_{nSP} = 4.1 DATE: 21MAY86

CONFIGURATION NO.= 3-D ξ_{SP} = 1.0 PILOT: A

GEARING = 0.500 FCS = 0.5(20.0)/(10.0) IP: HARPER

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light to medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Quick
- FINAL RESPONSE: Quick
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Not required
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Low
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: None.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 7	RUN NO.= 4	ω_{nSP} = 4.1	DATE: 21MAY86
CONFIGURATION NO.= 3-D		ξ_{SP} = 1.0	PILOT: A
GEARING = 0.500		FCS = 0.5(20.0)/(10.0)	IP: HARPER

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light to medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Quick
- FINAL RESPONSE: Quick
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Not required
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Low
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: None.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 14 RUN NO.= 4 ω_{nSP} = 4.1 DATE: 27MAY86
CONFIGURATION NO.= 3-D ξ_{SP} = 1.0 PILOT: C
GEARING = 0.500 FCS = 0.5(20.0)/(10.0) IP: EASTER

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium
- PITCH SENSITIVITY: Medium to high

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Fast
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: None
- PIO TENDENCY: None

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS:
- GOOD FEATURES: Aircraft flew well both final and flare. Aircraft responds well to pilot

INFLIGHT PILOT COMMENT CARD

FLT NO.= 12 RUN NO.= 1	ω_{nSP} = 4.1	DATE: 27MAY86
CONFIGURATION NO.= 3-1	ξ_{SP} = 1.0	PILOT: A
GEARING = 0.421	FCS = 1	IP: HARPER

PIO RATING = 3 C-H RATING = 5 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light to medium
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory except in flare
- PILOT COMPENSATION: Lower gain
- PIO TENDENCY: Light low frequency bobble in flare

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Adequate (± 500 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High gain
- SPECIAL CONTROL: Reduced gain
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Low frequency, small amplitude bobble degraded spot landing.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 9 RUN NO.= 4 ω_{nSP} = 4.1 DATE: 22MAY86
CONFIGURATION NO.= 3-1 ξ_{SP} = 1.0 PILOT: B
GEARING = 0.421 FCS = 1 IP: EASTER

PIO RATING = 2 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Slightly high pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Quick response
- FINAL RESPONSE: Quick response
- PREDICTABILITY: Good
- PILOT COMPENSATION: Slight compensation required to set pitch attitude
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: Had to position nose of aircraft with small pitch corrections
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: 2 kt tail wind
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Pitch movement characterized by small jerky motions, did not affect task performance.
- GOOD FEATURES: No lag or delay was noted.
  The motion was fast with no residual overshoots.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 11	RUN NO.= 1	ω_{nSP} = 4.1	DATE: 27MAY86
CONFIGURATION NO. = 3-1		ξ_{SP} = 1.0	PILOT: C
GEARING = 0.421		FCS = 1	IP: EASTER

PIO RATING = 2 C-H RATING = 4 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Less than satisfactory due to overshoots
- PILOT COMPENSATION: Low to medium gain shaping
- PIO TENDENCY: Low

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Adequate (± 500 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: Lower gain
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: Medium frequency sustained oscillation.
- GOOD FEATURES: The amplitude of the oscillation was small and pilot could control the aircraft through the oscillation.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 16 RUN NO.= 3 ω_{nSP} = 4.1 DATE: 29MAY86
CONFIGURATION NO.= 3-3 ξ_{SP} = 1.0 PILOT: A
GEARING = 0.421 FCS = 4.0/(4.0) IP: EASTER

PIO RATING = 3 C-H RATING = 7 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS:

- FORCES: Medium
- PITCH SENSITIVITY: Low to medium

PITCH ATTITUDE CONTROL:

- INITIAL RESPONSE: Slow to medium
- FINAL RESPONSE: Slow
- PREDICTABILITY: Poor
- PILOT COMPENSATION: Stairstep aircraft down to touchdown
- PIO TENDENCY: Low

TASK PERFORMANCE:

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Dropped in
- AGGRESSIVENESS: High
- SPECIAL CONTROL: Stairstep flare to landing
- REASON APP. ABANDON: Handling qualities

ADDITIONAL FACTORS:

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS: Dropped in flare.
  Low amplitude medium frequency bobble in flare.
  Time lag between input and aircraft response.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 9	RUN NO.= 1	ω_{nSP} = 4.1	DATE: 22MAY86
CONFIGURATION NO.= 3-3		ξ_{SP} = 1.0	PILOT: B
GEARING = 0.421		FCS = 4.0/(4.0)	IP: EASTER

PIO RATING = 1　　C-H RATING = 2　　CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- •FORCES: Medium forces
- •PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- •INITIAL RESPONSE: Quick
- •FINAL RESPONSE: Quick
- •PREDICTABILITY: Satisfactory
- •PILOT COMPENSATION: Not required
- •PIO TENDENCY: None

TASK PERFORMANCE :

- •AIRSPEED CONTROL: Desired (± 5 kt)
- •TOUCH DOWN POINT: Desired (± 250 feet)
- •RUNWAY ALIGNMENT: Desired (± 5 feet)
- •TOUCH DOWN SINK RATE: Low
- •AGGRESSIVENESS: Medium
- •SPECIAL CONTROL: None
- •REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- •WIND: 2 kt tail wind
- •TURBULENCE: No factor
- •LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- •MAJOR PROBLEMS: None.
- •GOOD FEATURES: Overall, no delay or lag was noted.
  Pilot felt in phase with input.
  Intentional inputs during flare did not induce PIO.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 15 RUN NO.= 1 ω_{nSP} = 4.1 DATE: 29MAY86
CONFIGURATION NO.= 3-3 ξ_{SP} = 1.0 PILOT: C
GEARING = 0.421 FCS = 4.0/(4.0) IP: HARPER

PIO RATING = 1 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: None
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Long due to high airspeed
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High gain
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS:
- GOOD FEATURES: Good flying qualities.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 7	RUN NO.= 1	ω_{nSP} = 4.1	DATE: 21MAY86
CONFIGURATION NO.= 3-6		ζ_{SP} = 1.0	PILOT: A
GEARING = 0.421		FCS = 256/[0.7, 16]	IP: HARPER

PIO RATING = 2 C-H RATING = 5 CONFIDENCE RATING = B

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium to high forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Slow and sluggish
- FINAL RESPONSE: Medium
- PREDICTABILITY: Less than satisfactory
- PILOT COMPENSATION: Gains reduced slightly
- PIO TENDENCY: Slight

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Adequate (± 500 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: None
- REASON APP. ABANDON: Handling qualities; high pitch force

ADDITIONAL FACTORS :
- WIND: 50 degrees cross wind at 15 kt
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: Light roll ratchet noticed in offset correction

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: High stick forces. Confidence rating B due to cross wind and heavy fuel weight.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 14	RUN NO.= 1	ω_{nSP} = 4.1	DATE: 28MAY86
CONFIGURATION NO.= 3-6		ξ_{SP} = 1.0	PILOT: C
GEARING = 0.421		FCS = 256/[0.7, 16]	IP: EASTER

PIO RATING = 2 C-H RATING = 4 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium
- PITCH SENSITIVITY: Medium to high

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Fast
- FINAL RESPONSE: Medium
- PREDICTABILITY: A little bobble tendency in flare
- PILOT COMPENSATION: Low gain shaping
- PIO TENDENCY: Low. A little bobble tendency in flare

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Long due to flare
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Smooth
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: Lower gain to avoid undesired motion
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor (tail wind at 4 kt)
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Aircraft showed undesirable bobbling motion under high gain, so pilot was required to lower the gain.
- GOOD FEATURES: Good aircraft until flare

INFLIGHT PILOT COMMENT CARD

FLT NO.= 8	RUN NO.= 3	ω_{nSP} = 4.1	DATE: 22MAY86
CONFIGURATION NO.= 3-8		ζ_{SP} = 1.0	PILOT: A
GEARING= 0.421		FCS = 81/[0.7, 9]	IP: HARPER

PIO RATING = 4 C-H RATING = 8 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light to medium
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Less than satisfactory
- PILOT COMPENSATION: Reduced gain required
- PIO TENDENCY: Moderate

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired(± 5 kt)
- TOUCH DOWN POINT: Less than adequate
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: High
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: Reduced gain in flare
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: Slight turbulence induced oscillations
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Sustained medium amplitude, medium frequency PIO during tight control (lightly damped).

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 13 RUN NO.= 3 ω_{nSP} = 4.1 DATE: 27MAY86
CONFIGURATION NO.= 3-8 ξ_{SP} = 1.0 PILOT: B
GEARING = 0.421 FCS = 81/[0.7, 9] IP: EASTER

PIO RATING = 3 C-H RATING = 5 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS:

- FORCES: Medium
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL:

- INITIAL RESPONSE: Fast
- FINAL RESPONSE: Medium
- PREDICTABILITY: Fair
- PILOT COMPENSATION: Freeze stick to stop movement
- PIO TENDENCY: Medium

TASK PERFORMANCE:

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Long
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS:

- WIND: No factor
- TURBULENCE: Light
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS: More of an undesireable motion than PIO. High frequency, low amplitude bobbling during small corrections in flare. This made touchdown point accuracy more difficult. No delays or lag noted. Motions were too jerky for landing.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 5	RUN NO.= 3	ω_{nSP} = 4.1	DATE: 21MAY86
CONFIGURATION NO.= 3-8		ξ_{SP} = 1.0	PILOT: C
GEARING = 0.421		FCS = 81/[0.7, 9]	IP: EASTER

PIO RATING = 4 C-H RATING = 8 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium response rate
- FINAL RESPONSE: Medium response rate
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Reduced gain required
- PIO TENDENCY: Medium

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: No touch down
- RUNWAY ALIGNMENT: No touch down
- TOUCH DOWN SINK RATE: No touch down
- AGGRESSIVENESS: Very high
- SPECIAL CONTROL: Lower gain
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Sustained, high frequency, medium amplitude PIO in flare.
- GOOD FEATURES: Good control harmony and coordination

INFLIGHT PILOT COMMENT CARD

FLT NO.= 9	RUN NO.= 2	ω_{nSP} = 4.1	DATE: 22MAY86
CONFIGURATION NO.= 3-12		ζ_{SP} = 1.0	PILOT: B
GEARING = 0.421		FCS = 4/[0.7, 2]	IP: EASTER

PIO RATING = 4 C-H RATING = 7 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Sluggish response
- FINAL RESPONSE: Sluggish response
- PREDICTABILITY: Poor
- PILOT COMPENSATION: Lead compensation required
- PIO TENDENCY: High

TASK PERFORMANCE :

- AIRSPEED CONTROL: Less than adequate
- TOUCH DOWN POINT: Less than adequate
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: Medium to high
- SPECIAL CONTROL: Let go of stick to stop PIO
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: 2 kt tail wind
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Low frequency PIO.
  Pilot was out of phase during round-out to flare,
  ± 5 degrees pitch, did not seem divergent.
  Aircraft response was sluggish and lagging.

- GOOD FEATURES: This low frequency PIO probably could be controlled with practice.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 15	RUN NO.= 2	ω_{nSP} = 4.1	DATE: 29MAY86
CONFIGURATION NO.= 3-12		ζ_{SP} = 1.0	PILOT: C
GEARING = 0.421		FCS = 4/[0.7, 2]	IP: HARPER

PIO RATING = 5 C-H RATING = 9 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium forces
- PITCH SENSITIVITY: Low

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Sluggish
- FINAL RESPONSE: Sluggish
- PREDICTABILITY: Poor
- PILOT COMPENSATION: High degree of compensation
- PIO TENDENCY: High

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: No touch down
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: No touch down
- AGGRESSIVENESS: High gain
- SPECIAL CONTROL: N/A
- REASON APP. ABANDON: Divergent low frequency PIO

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: Slow response and time lag caused a low frequency divergent PIO.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 7	RUN NO.= 2	ω_{nSP} = 4.1	DATE: 21MAY86
CONFIGURATION NO.= 3-13		ξ_{SP} = 1.0	PILOT: A
GEARING = 0.421		FCS = 9/[0.7, 3]	IP: HARPER

PIO RATING = 4 C-H RATING = 10 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light forces
- PITCH SENSITIVITY: Medium to high pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Slow and sluggish
- FINAL RESPONSE: Medium
- PREDICTABILITY: Less than satisfactory
- PILOT COMPENSATION: Had to freeze stick to eliminate PIO
- PIO TENDENCY: High

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: No touch down
- RUNWAY ALIGNMENT: No touch down
- TOUCH DOWN SINK RATE: No touch down
- AGGRESSIVENESS: Slightly aggressive
- SPECIAL CONTROL: Freeze stick in flare
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: 60 degrees cross wind at 10 gusting to 18 kt
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Medium frequency, medium amplitude (± 5 degrees pitch) sustained PIO in flare.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 14	RUN NO.= 3	ω_{nSP} = 4.1	DATE: 27MAY86
CONFIGURATION NO.= 3-13		ξ_{SP} = 1.0	PILOT: C
GEARING = 0.421		FCS = 9/[0.7, 3]	IP: EASTER

PIO RATING = 5 C-H RATING = 10 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS:
- •FORCES: Medium to heavy
- •PITCH SENSITIVITY: Low

PITCH ATTITUDE CONTROL:
- •INITIAL RESPONSE: Sluggish
- •FINAL RESPONSE: Sluggish
- •PREDICTABILITY: Poor
- •PILOT COMPENSATION: High, to input a lower stick gain
- •PIO TENDENCY: High

TASK PERFORMANCE:
- •AIRSPEED CONTROL: Desired (± 5 kt)
- •TOUCH DOWN POINT: No touch down
- •RUNWAY ALIGNMENT: Desired (± 5 feet)
- •TOUCH DOWN SINK RATE: No touch down
- •AGGRESSIVENESS: High
- •SPECIAL CONTROL: Lowered gain in flare
- •REASON APP. ABANDON: Divergent PIO on flare

ADDITIONAL FACTORS:
- •WIND: No factor
- •TURBULENCE: No factor
- •LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION:
- •MAJOR PROBLEMS: Aircraft entered divergent low frequency PIO during flare.
- •GOOD FEATURES: Aircraft flew well on final.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 7 RUN NO.= 3 ω_{nSP} = 3.0 DATE: 21MAY86
CONFIGURATION NO.= 4-1 ξ_{SP} = 0.74 PILOT: A
GEARING = 0.200 FCS = 1 IP: HARPER

PIO RATING = 1 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light to medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Quick
- FINAL RESPONSE: Quick
- PREDICTABILITY: Desired
- PILOT COMPENSATION: Not required
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Long due to gusty wind
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: 50 degrees cross wind at 6 gusting to 14 kt
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: None.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 17	RUN NO= 4	ω_{nSP} = 3.0	DATE: 29MAY86
CONFIGURATION NO.= 4-1		ζ_{SP} = 0.74	PILOT: B
GEARING = 0.200		FCS = 1	IP: HARPER

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Good
- PILOT COMPENSATION: Low
- PIO TENDENCY: None

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: 210 / 10 G 18
- TURBULENCE: Moderate
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: None

- GOOD FEATURES: Felt like normal aircraft. No problems noted.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 4	RUN NO.= 1	ω_{nSP} = 3.0	DATE: 17MAY86
CONFIGURATION NO.= 4-1		ζ_{SP} = 0.74	PILOT: C
GEARING = 0.200		FCS = 1	IP: EASTER

PIO RATING = 1 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light forces
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: A little reduced gain required
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Adequate (± 500 feet) 50 % of time
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: High
- SPECIAL CONTROL: Reduced gain
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Aircraft tended to float.
  Adequate performance due to long flare, not a function of aircraft response.

- GOOD FEATURES: Good control harmony and coordination.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 9	RUN NO.= 3	ω_{nSP} = 3.0	DATE: 22MAY86
CONFIGURATION NO.= 4-2		ζ_{SP} = 0.74	PILOT: B
GEARING = 0.200		FCS = 10.0/(10.0)	IP: EASTER

PIO RATING = 1 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Quick response
- FINAL RESPONSE: Quick response
- PREDICTABILITY: Good
- PILOT COMPENSATION: Not required
- PIO TENDENCY: None

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Low to medium
- SPECIAL CONTROL: Not required
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: None.
- GOOD FEATURES: Initial response was fast with no lag or delay. No overshoots were observed. Small corrections during flare did not induce PIO or undesireable motion.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 16	RUN NO.= 4	ω_{nSP} = 3.0	DATE: 29MAY86
CONFIGURATION NO.= 4-2		ζ_{SP} = 0.74	PILOT: A
GEARING = 0.200		FCS = 10.0/(10.0)	IP: EASTER

PIO RATING = 1 C-H RATING = 3 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium
- PITCH SENSITIVITY: Medium

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Good
- PILOT COMPENSATION: Low
- PIO TENDENCY: None

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS. Medium gain
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS:
- GOOD FEATURES: Flies like normal aircraft

INFLIGHT PILOT COMMENT CARD

FLT NO.= 14	RUN NO.= 2	ω_{nSP} = 3.0	DATE: 26MAY86
CONFIGURATION NO.= 4-2		ζ_{SP} = 0.74	PILOT: C
GEARING = 0.200		FCS = 10.0/(10.0)	IP: EASTER

PIO RATING = 2 C-H RATING = 4 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS:
- FORCES: Medium
- PITCH SENSITIVITY: Low to medium

PITCH ATTITUDE CONTROL:
- INITIAL RESPONSE: Sluggish
- FINAL RESPONSE: Medium
- PREDICTABILITY: A little bobble tendency at initial response during flare
- PILOT COMPENSATION: Low gain
- PIO TENDENCY: A little undesired bobble in flare

TASK PERFORMANCE:
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: Lower gain input required
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS:
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION:
- MAJOR PROBLEMS: Undesirable, medium frequency bobble motion during flare. Aircraft initial response tended to be slow.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 3 RUN NO.= 3 ω_{nSP} = 1.7 DATE: 17MAY86
CONFIGURATION NO.= 5-1 ξ_{SP} = 0.68 PILOT: A
GEARING = 0.100 FCS = 1 IP: PARRAG

PIO RATING = 1 C-H RATING = 2 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Light forces
- PITCH SENSITIVITY: Low to medium pitch sensitivity

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Medium response rate
- FINAL RESPONSE: Medium response rate
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Not required
- PIO TENDENCY: None

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: None
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: None
- GOOD FEATURES: No PIO tendency

INFLIGHT PILOT COMMENT CARD

FLT NO.= 10	RUN NO.= 1	ω_{nSP} = 1.7	DATE: 22MAY86
CONFIGURATION NO.= 5-1		ξ_{SP} = 0.68	PILOT: C
GEARING = 0.100		FCS = 1	IP: HARPER

PIO RATING = 1 C-H RATING = 5 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Medium to heavy forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Medium
- FINAL RESPONSE: Medium
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Not required
- PIO TENDENCY: None

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Longer than adequate
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High
- SPECIAL CONTROL: Small conpensation required to avoid float
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :
- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: Desired performance not attainable due to float tendency in flare. No undesirable motions or PIOs were noted.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 8	RUN NO.= 2	ω_{nSP} = 1.7	DATE: 22MAY86
CONFIGURATION NO.= 5-9		ξ_{SP} = 0.68	PILOT: A
GEARING= 0.100		FCS = 36/[0.7, 6]	IP: HARPER

PIO RATING = 4 C-H RATING = 7 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium
- PITCH SENSITIVITY: High pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Medium to fast
- FINAL RESPONSE: Medium to fast.
- PREDICTABILITY: Less than satisfactory
- PILOT COMPENSATION: Reduced gain required
- PIO TENDENCY: Yes. With high gain input.

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired(± 5 kt)
- TOUCH DOWN POINT: Less than adequate
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Medium
- AGGRESSIVENESS: Medium
- SPECIAL CONTROL: Stick freeze in flare to stop PIO
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: Slight turbulence induced oscillations
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Medium amplitude (± 5 degrees pitch), high frequency PIO with tight control.
- GOOD FEATURES: PIO quickly dies out with reduced inputs.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 13	RUN NO.= 4	ω_{nSP} = 1.7	DATE: 27MAY86
CONFIGURATION NO.= 5-9		ξ_{SP} = 0.68	PILOT: B
GEARING = 0.100		FCS = 36/[0.7, 6]	IP: EASTER

PIO RATING = 5 C-H RATING = 8 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :
- FORCES: Heavier gradient than desired, didn't affect performance
- PITCH SENSITIVITY: Low

PITCH ATTITUDE CONTROL :
- INITIAL RESPONSE: Slow
- FINAL RESPONSE: Slow
- PREDICTABILITY: Poor
- PILOT COMPENSATION: High
- PIO TENDENCY: High

TASK PERFORMANCE :
- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Less than adequate
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: High
- SPECIAL CONTROL: Freeze stick to stop PIO
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :
- WIND: No factor (head wind at 10 kt)
- TURBULENCE: Light
- LAT-DIR PERFORMANCE: Slow, some nose wonder.

SUMMARIZE EVALUATION :
- MAJOR PROBLEMS: Sluggish response on final. During flare, got out of phase with inputs and response. Oscillations were low frequency and starting to become divergent. Very difficult to put on the ground. Lag was noticeable on final but was only a problem during flare.

- GOOD FEATURES: High stick forces were not a factor during flare.

INFLIGHT PILOT COMMENT CARD

FLT NO.= 5	RUN NO.= 2	ω_{nSP} = 1.7	DATE: 21MAY86
CONFIGURATION NO.= 5-9		ξ_{SP} = 0.66	PILOT: C
GEARING = 0.100		FCS = 36/[0.7, 6]	IP: EASTER

PIO RATING = 4 C-H RATING = 7 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Low response rate
- FINAL RESPONSE: Medium response rate
- PREDICTABILITY: Satisfactory
- PILOT COMPENSATION: Reduced gain required with PIO
- PIO TENDENCY: Medium

TASK PERFORMANCE :

- AIRSPEED CONTROL: Adequate (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: High sink rate
- AGGRESSIVENESS: High
- SPECIAL CONTROL: Lower gain to control PIO
- REASON APP. ABANDON: PIO (1 of 3 approaches)

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Low frequency PIO during flare. Had to freeze stick and let aircraft drop to hit touch down point, not desirable.

- GOOD FEATURES: Good control harmony and coordination

INFLIGHT PILOT COMMENT CARD

FLT NO.= 3	RUN NO.= 2	ω_{nSP} = 1.7	DATE: 17MAY86
CONFIGURATION NO.= 5-10		ξ_{SP} = 0.68	PILOT: A
GEARING = 0.100		FCS = 16/[0.7,4]	IP: PARRAG

PIO RATING = 5 C-H RATING = 10 CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Light forces
- PITCH SENSITIVITY: Medium to high sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Sluggish
- FINAL RESPONSE: Abrupt
- PREDICTABILITY: Poor
- PILOT COMPENSATION: Required pilot to lead inputs due to sluggishness
- PIO TENDENCY: High

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: No touch down
- RUNWAY ALIGNMENT: No touch down
- TOUCH DOWN SINK RATE: No touch down
- AGGRESSIVENESS: High
- SPECIAL CONTROL: No flare
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Large amplitude (± 10 degrees pitch), low frequency PIO in flare. Apparent time delay in system response.

- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 6 RUN NO.= 1 ω_{nSP} = 1.7 DATE: 21MAY56

CONFIGURATION NO.= 5-11 ξ_{SP} = 0.68 PILOT: B

GEARING = 0.100 FCS = 65536/[0.93,16][0.38,16] IP: EASTER

PIO RATING = 4 C-H RATING = 7 CONFIDENCE RATING = B

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium forces
- PITCH SENSITIVITY: Medium pitch sensitivity

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Slow response rate
- FINAL RESPONSE: Medium response rate
- PREDICTABILITY: Poor because of delay
- PILOT COMPENSATION: Lead compensation required
- PIO TENDENCY: High

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Less than adequate
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Low
- AGGRESSIVENESS: Medium until flare, then high
- SPECIAL CONTROL: Cross wind raised gain, compensation required
- REASON APP. ABANDON: PIO

ADDITIONAL FACTORS :

- WIND: 30 degrees cross wind at 15 kt
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Precise control was difficult with delay. Tended to over control to compensate for delay. PIO did not seem to be divergent. Confidence rating B because first two approaches were disengaged too early to see very much.
- GOOD FEATURES:

INFLIGHT PILOT COMMENT CARD

FLT NO.= 11	RUN NO.= 2	ω_{nSP} = 1.7	DATE: 27MAY86
CONFIGURATION NO. = 5-11		ξ_{SP} = 0.68	PILOT: C
GEARING = 0.100		FCS = 65536/[0.93,16][0.38,16]	IP: EASTER

PIO RATING = 3   C-H RATING = 5   CONFIDENCE RATING = A

FEEL SYSTEM CHARACTERISTICS :

- FORCES: Medium to heavy
- PITCH SENSITIVITY: Low

PITCH ATTITUDE CONTROL :

- INITIAL RESPONSE: Sluggish
- FINAL RESPONSE: Sluggish
- PREDICTABILITY: Poor
- PILOT COMPENSATION: Medium to high compensation required
- PIO TENDENCY: Low

TASK PERFORMANCE :

- AIRSPEED CONTROL: Desired (± 5 kt)
- TOUCH DOWN POINT: Desired (± 250 feet)
- RUNWAY ALIGNMENT: Desired (± 5 feet)
- TOUCH DOWN SINK RATE: Dropped in
- AGGRESSIVENESS: Medium gain
- SPECIAL CONTROL: Slow input required
- REASON APP. ABANDON: N/A

ADDITIONAL FACTORS :

- WIND: No factor
- TURBULENCE: No factor
- LAT-DIR PERFORMANCE: No factor

SUMMARIZE EVALUATION :

- MAJOR PROBLEMS: Slow response in pitch during flare.
  Desired performance only attainable by dropping aircraft in.

- GOOD FEATURES: If pilot lowered his gain, PIO tended to be convergent
  and he could control the aircraft and land safely.

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APPENDIX B

LONGITUDINAL CHARACTERISTICS OF FLIGHT MODEL

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Configurations	2-1	3-1	4-1	5-1
ω_{SP}	2.41	4.22	3.04	1.70
ζ_{SP}	0.63	0.97	0.73	0.68
X_u	-.041	-.041	-.041	-.041
X_w	0.11	0.11	0.11	0.11
X_q	0.0	0.0	0.0	0.0
$X_{\delta e}$	.0032	.0032	.0032	.0032
Z_u	-.26	-.26	-.26	-.26
Z_w	-.80642	-.92116	-.84168	-.76979
Z_q	0	0	0	0
$Z_{\delta e}$	1.1	1.1	1.1	1.1
M_u	0	0	0	0
M_w	-.01960	-.005474	-.03040	-.000838
M_q	-2.26560	-7.27889	-3.59834	-1.54220
$M_{\delta e}$	0.33685	0.33685	0.33685	0.33685
θ_0	4.5	4.5	4.6	4.5

The fourth order longitudinal characteristic equation of flight test is:

$$\Delta = s^4 + As^3 + Bs^2 + Cs + D \qquad [1]$$

where

$$A = -M_q - Z_w - Z_u$$

$$B = X_u (M_q + Z_w) + M_q Z_w - U_0 M_w - X_w Z_u + W_0 M_u$$

$$C = -X_u (Z_w M_q - U_0 M_w) + Z_u (X_w M_q + W_0 M_w) - M_u (U_0 X_w - W_0 Z_w - g\cos\theta_0) + g M_w \sin\theta_0$$

$$D = g\cos\theta_0 (Z_u M_w - M_u Z_w) - gX_u M_w \sin\theta_0$$

The numerators of the transfer functions important to PIO study was developed

Pitch to Elevator Deflection Numerator:

$$N^{\theta}_{\delta e}(s) = \begin{vmatrix} (s-X_u) & -X_w\, U_0 & X_{\delta e} \\ Z_u / U_0 & (s-Z_w) & Z_{\delta e}/U_0 \\ -M_u & -M_w\, U_0 & M_{\delta e} \end{vmatrix}$$

$$N^{\theta}_{\delta e}(s) = A_\theta s^2 + B_\theta\, s + C_\theta$$

where [2]

$$A_\theta = M_{\delta e}$$
$$B_\theta = X_{\delta e} M_u + Z_{\delta e} M_w - M_{\delta e}(X_u + Z_w)$$
$$C_\theta = X_{\delta e}(Z_u M_w - M_u Z_w) + Z_{\delta e}(X_w M_u - X_u M_w) + M_{\delta e}(Z_w X_u - X_w Z_u)$$

Angle-of-Attack to Elevator Deflection Numerator: This transfer function is neede to find the normal acceleration transfer function

$$N^{\alpha}_{\delta e}(s) = \begin{vmatrix} (s-X_u) & X_{\delta e} & (W_0 s + g\cos\theta_0) \\ -Z_u / U_0 & Z_{\delta e}/U_0 & (-U_0 s + g\sin\theta_0)/U_0 \\ -M_u & -M_{\delta e} & (s^2 - M_q s) \end{vmatrix}$$

$$N^{\alpha}_{\delta e}(s) = A_\alpha s^3 + B_\alpha s^2 + C_\alpha s + D_\alpha$$

Where [3]

$$A_\alpha = z_{\delta e}/U_0$$
$$B_\alpha = [X_{\delta e} Z_u - Z_{\delta e}(M_q + X_u) + M_{\delta e} U_0]/U_0$$
$$C_\alpha = [X_{\delta e}\{-Z_u M_q + U_0 M_u\} + Z_{\delta e}(X_u M_q + W_0 M_u) + M_{\delta e}(-g\sin\theta_o - W_0 Z_u)]/U_0$$
$$D_\alpha = [g\cos\theta_0 (M_u Z_{\delta e} - Z_u M_{\delta e}) + g\sin\theta_0 (M_{\delta e} X_u - M_u X_{\delta e})]/U_0$$

Pilot-felt Normal Acceleration to Elevator Deflection numerator:

$$q = s\theta$$
$$a_z = sw - u_0 q = sw - u_0 s\theta$$
$$a_{zp} = a_z - l_x s^2 \theta$$

where

a_z = downward (normal) acceleration of the aircraft center of gravity
a_{zp} = pilot-felt normal acceleration at the pilot station
l_x = pilot's location forward of the c.g.

$$a_{zp} = sw - sU_0\theta - s^2 l_x \theta$$
$$= s U_0 \alpha - sU_0 \theta - s^2 l_x \theta$$

$$N^{azp}_{\delta e}\,p(s) = sU_0\,N^{\alpha}_{\delta e}(s) - sU_0\,N^{\theta}_{\delta e}(s) - s^2\,l_x\,N^{\theta}_{\delta e}(s) \qquad [4]$$

$$N^{azp}_{\delta e}\,p(s) = A_{azp}\,s^4 + B_{azp}\,s^3 + C_{azp}\,s^2 + D_{azp}\,s$$

where

$$\begin{aligned}
A_{azp} &= U_0\,A_{\alpha} - l_x\,A_{\theta}\\
B_{azp} &= U_0\,(B_{\alpha} - A_{\theta}) - l_x\,B_{\theta}\\
C_{azp} &= U_0\,(C_{\alpha} - B_{\theta}) - l_x\,C_{\theta}\\
D_{azp} &= U_0\,(D_{\alpha} - C_{\theta})
\end{aligned}$$

Pitch loop Equivalent Command Gust Numerator:

$$N^{\alpha}_{\delta e}(s) = \begin{vmatrix} (s-X_u) & -X_w U_0 & -X_w \\ -Z_u/U_0 & s - Z_w & -Z_w/U_0 \\ -M_u & -U_0 M_w & -M_w + Mq\,s/U_0 \end{vmatrix}$$

$$N^{\theta}_{wg}\,p(s) = A_{\theta wg}\,s^3 + B_{\theta wg}\,s^2 + C_{\theta wg}\,s \qquad [5]$$

where

$$\begin{aligned}
A_{\theta wg} &= Mq/U_0\\
B_{\theta wg} &= -[M_w + (Z_w - X_u)\,M_q]/U_0\\
C_{\theta wg} &= X_u\,(M_w + Z_w\,M_q/U_0) - X_w\,(M_u + Z_u\,M_q/U_0)
\end{aligned}$$

The transfer function for each of the configurations were obtained using equations [1], [2], [4] and [5] and summarized below.

HAVE PIO Configuration 2-1

Δ = [0.15,0.17] [0.63,2.41]
$N^{\theta}_{\delta e}$ = 0.33685 (0.0845) (0.6990)
$N^{azp}_{\delta e}$ = -1.063 (0) (0.026) [-0.06, 6.86]
N^{θ}_{wg} = -0.0111 (0) (0.0108) (-1.019)

HAVE PIO Configuration 3-1

Δ = [0.17 , 0.16] [0.97 , 4.22]
$N^{\theta}_{\delta e}$ = 0.33685 (0.08470) (0.6987)
$N^{azp}_{\delta e}$ = -1.0626 (0) (0.0262) [-0.44, 6.85]
N^{θ}_{wg} = -0.0355 (0) (-0.6566) (-0.0048)

HAVE PIO Configuration 4-1

$\Delta = [\,0.16\,, 0.16\,]\;[\,0.73\,, 3.04\,]$
$N^{\theta}_{\delta e} = 0.33685\,(\,0.0846\,)\,(\,0.6988\,)$
$N^{azp}_{\delta e} = -1.0626\,(\,0\,)\,(\,0.0261\,)\,[\,-0.16, 6.86\,]$
$N^{\theta}_{wg} = -0.0176\,(\,0\,)\,(\,0.0084\,)\,(\,-0.9395\,)$

HAVE PIO Configuration 5-1

$\Delta = [\,0.16\,, 0.15\,]\;[\,0.68\,, 1.70\,]$
$N^{\theta}_{\delta e} = 0.33685\,(\,0.0845\,)\,(\,0.6989\,)$
$N^{azp}_{\delta e} = -1.0626\,(\,0\,)\,(\,0.0260\,)\,[\,-0.01, 6.86\,]$
$N^{\theta}_{wg} = -0.0075\,(\,0\,)\,(\,-0.0422\,)\,(\,-0.3432\,)$

APPENDIX C

PITCH RATE RESPONSE WITH STEP INPUT OF FLIGHT AND NON-REAL-TIME SIMULATION MODLES FOR EIGHTEEN CONFIGUARTIONS

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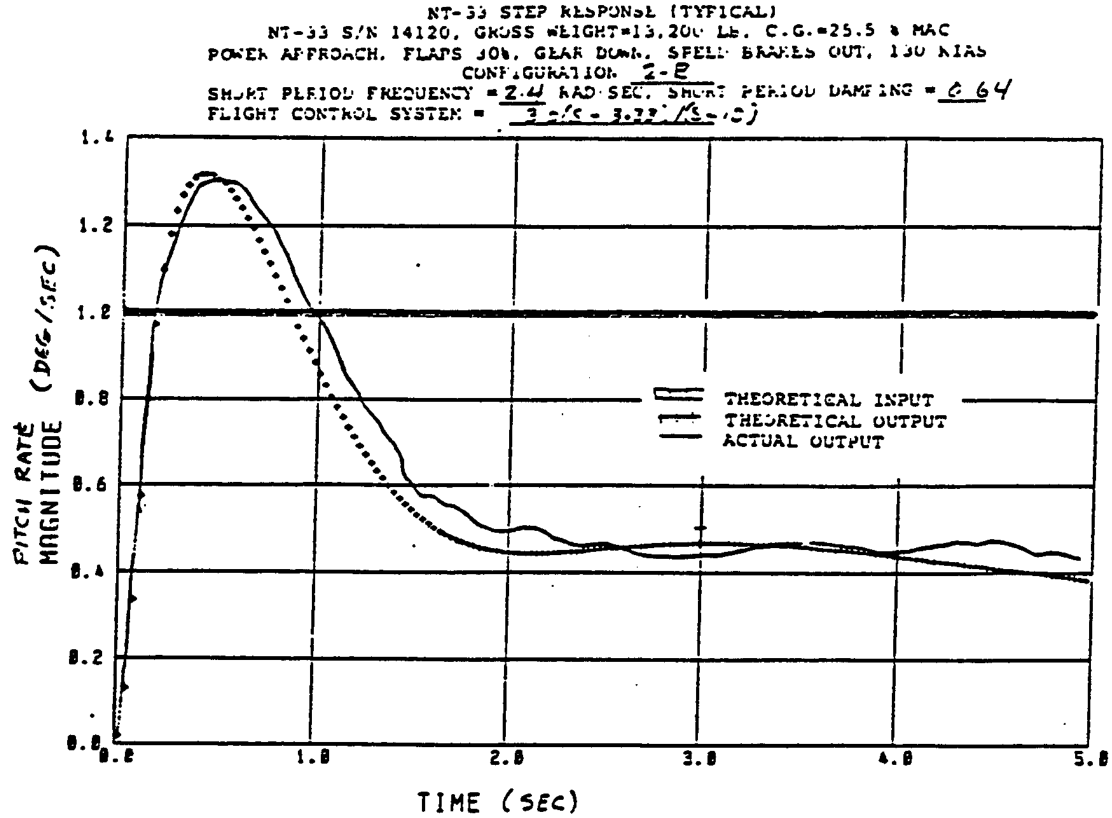

Figure D1. Step Response for Configuration 2-B.

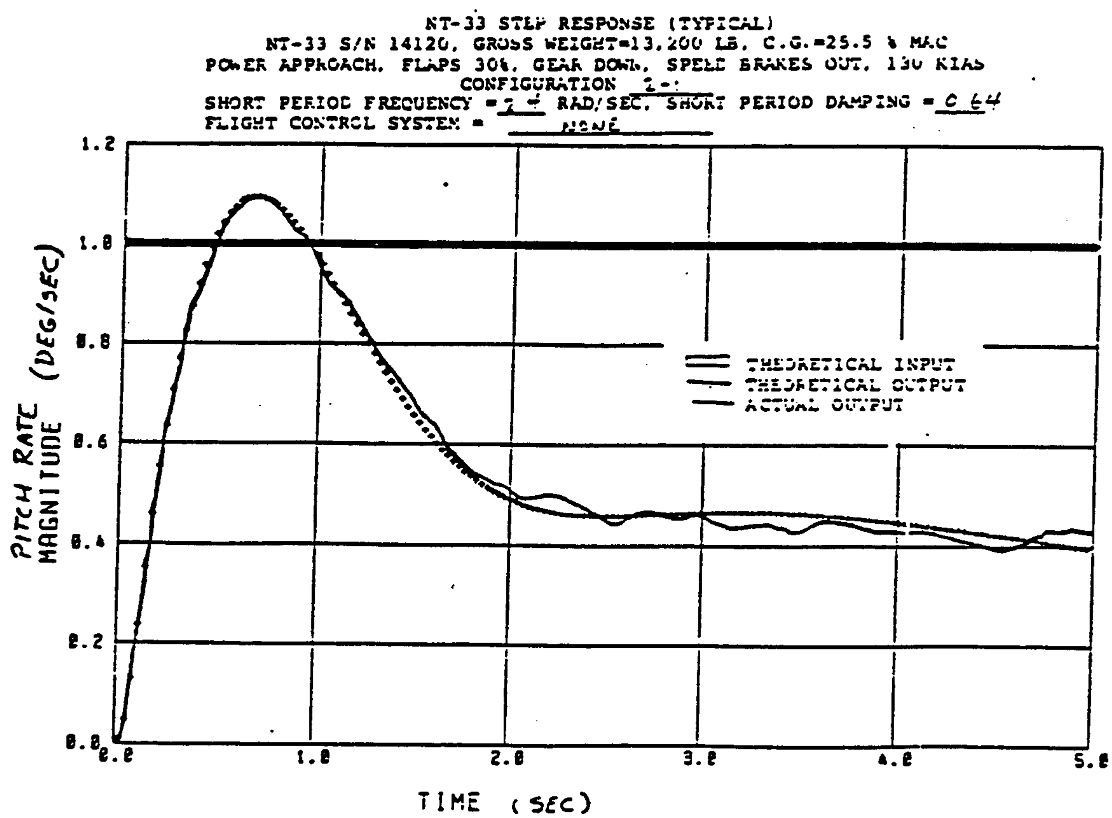

Figure D2. Step Response for Configuration 2-1.

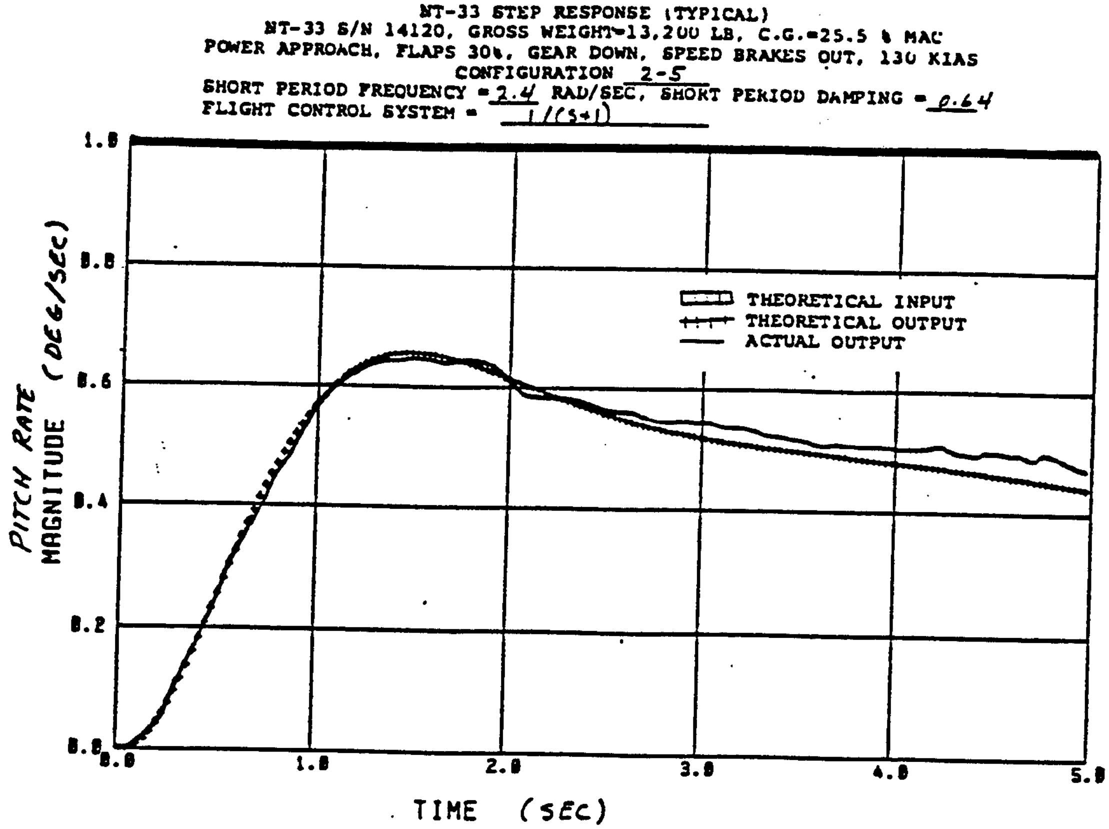

Figure D3. Step Response for Configuration 2-5.

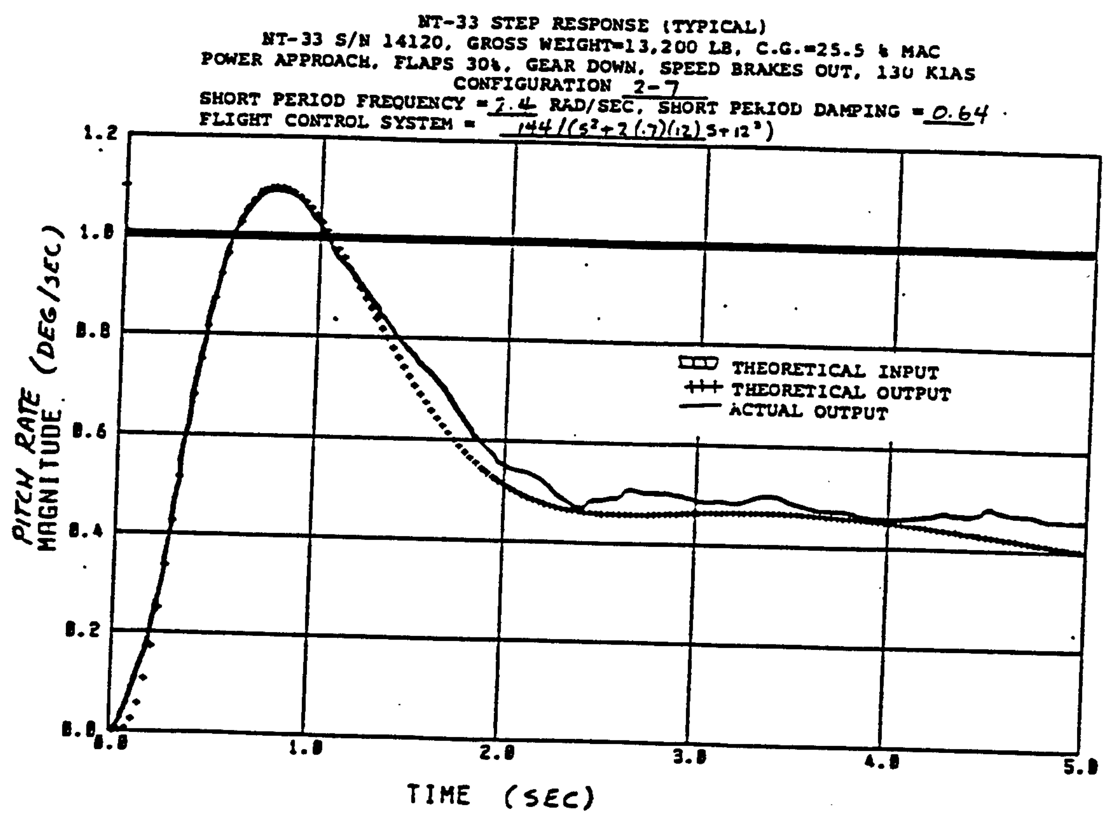

Figure D4. Step Response for Configuration 2-7.

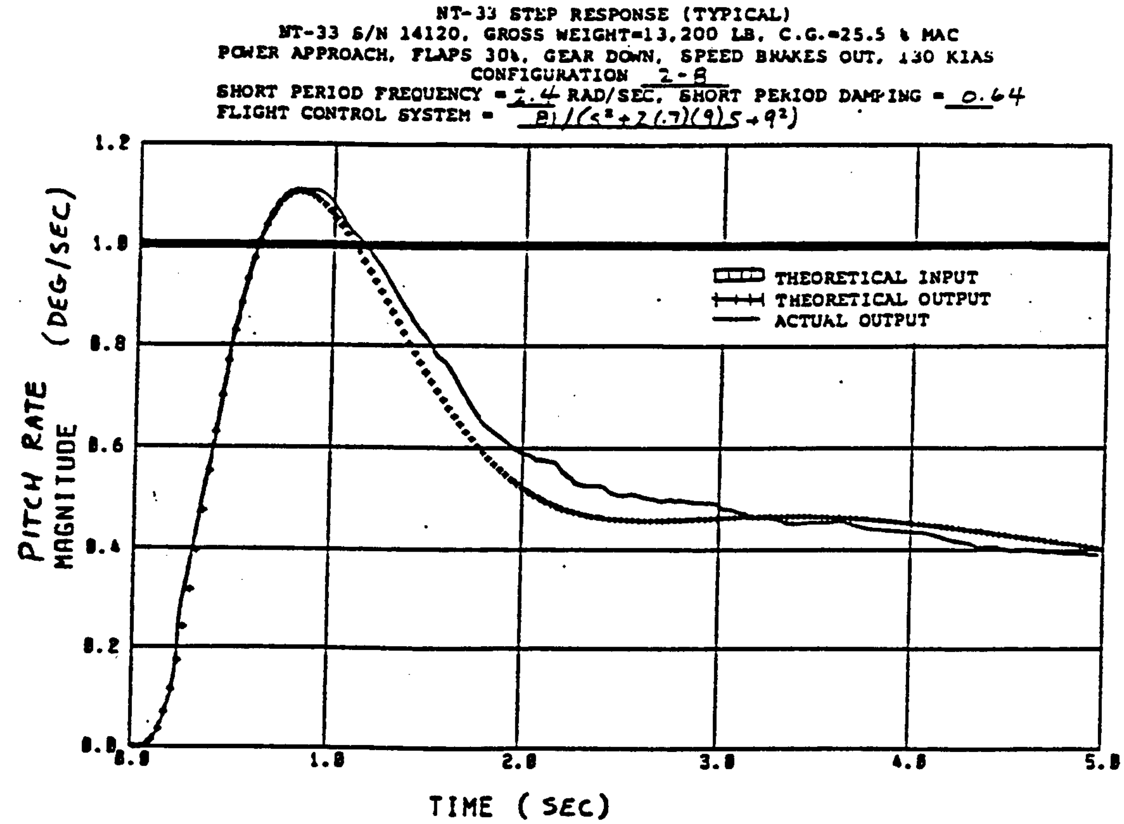

Figure D5. Step Response for Configuration 2-8.

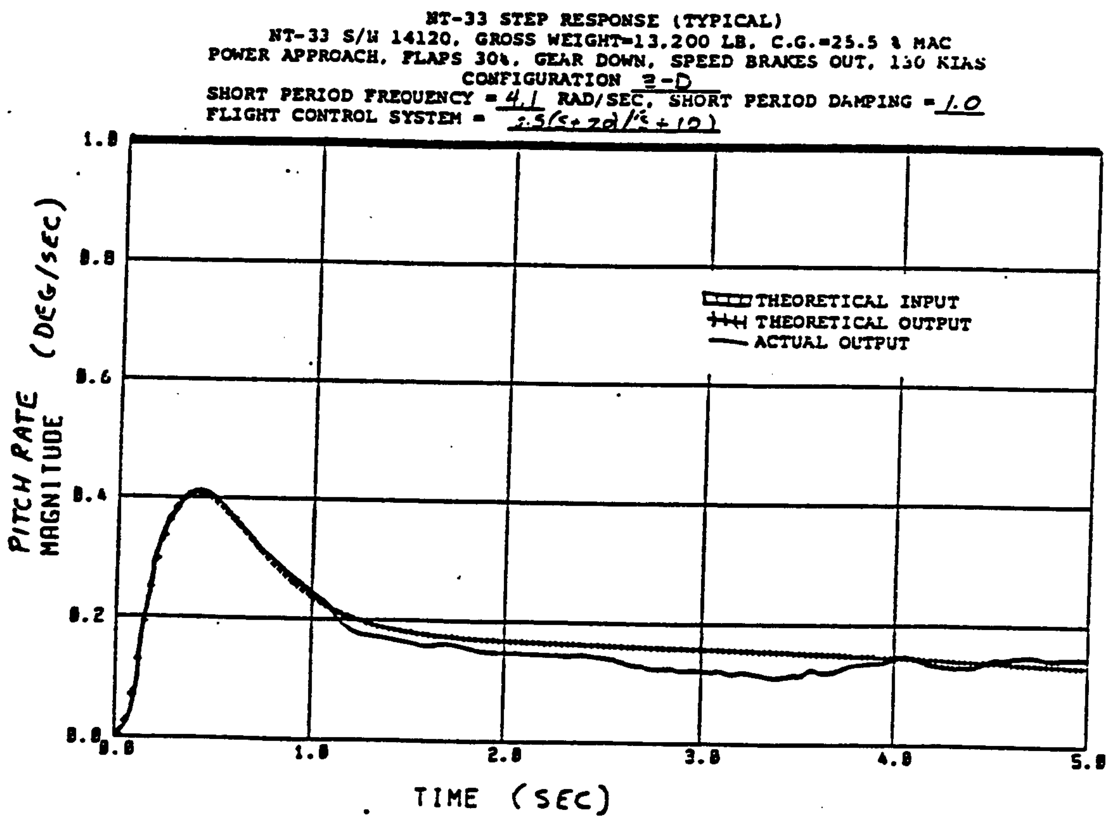

Figure D6. Step Response for Configuration 3-D.

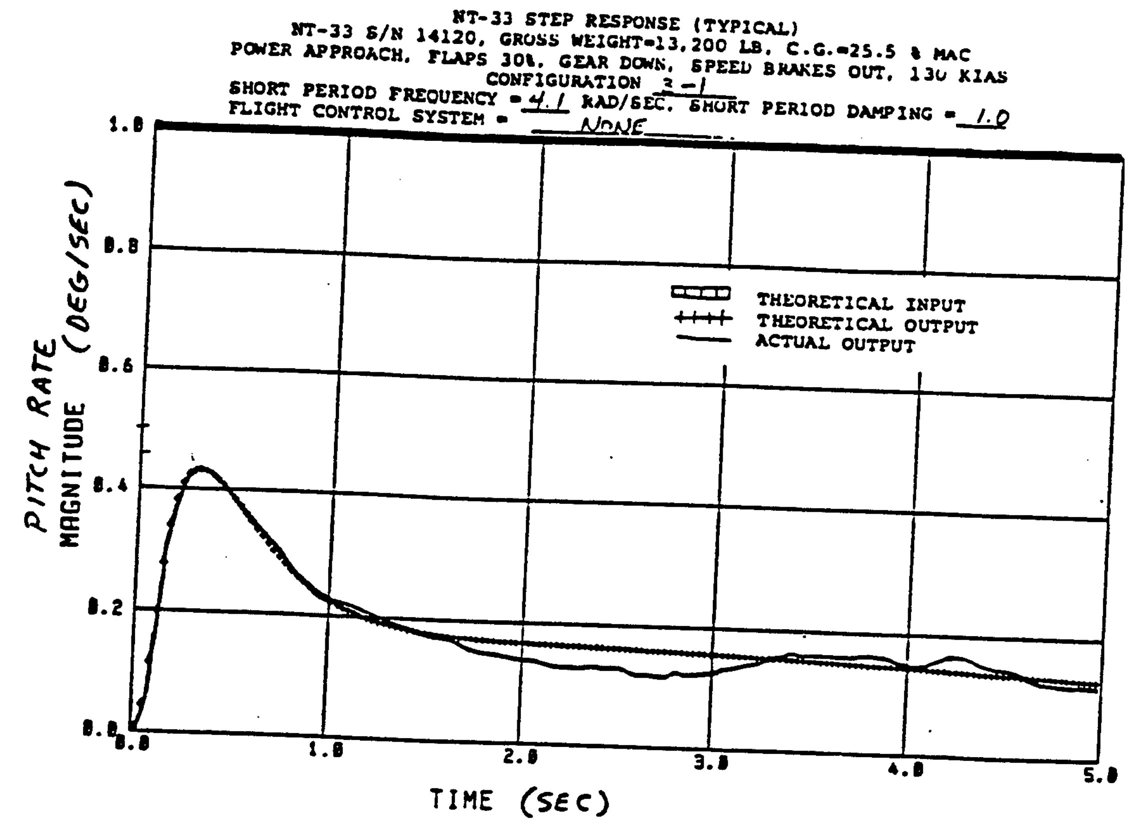

Figure D7. Step Response for Configuration 3-1.

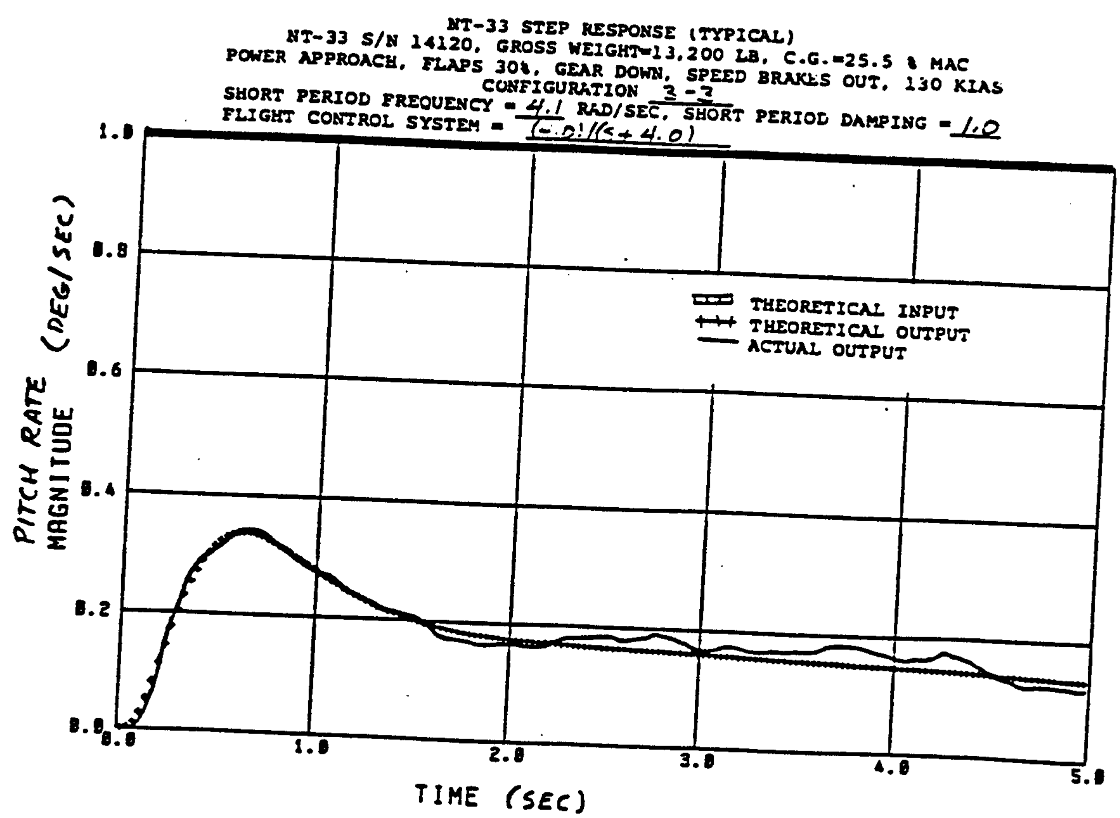

Figure D8. Step Response for Configuration 3-3.

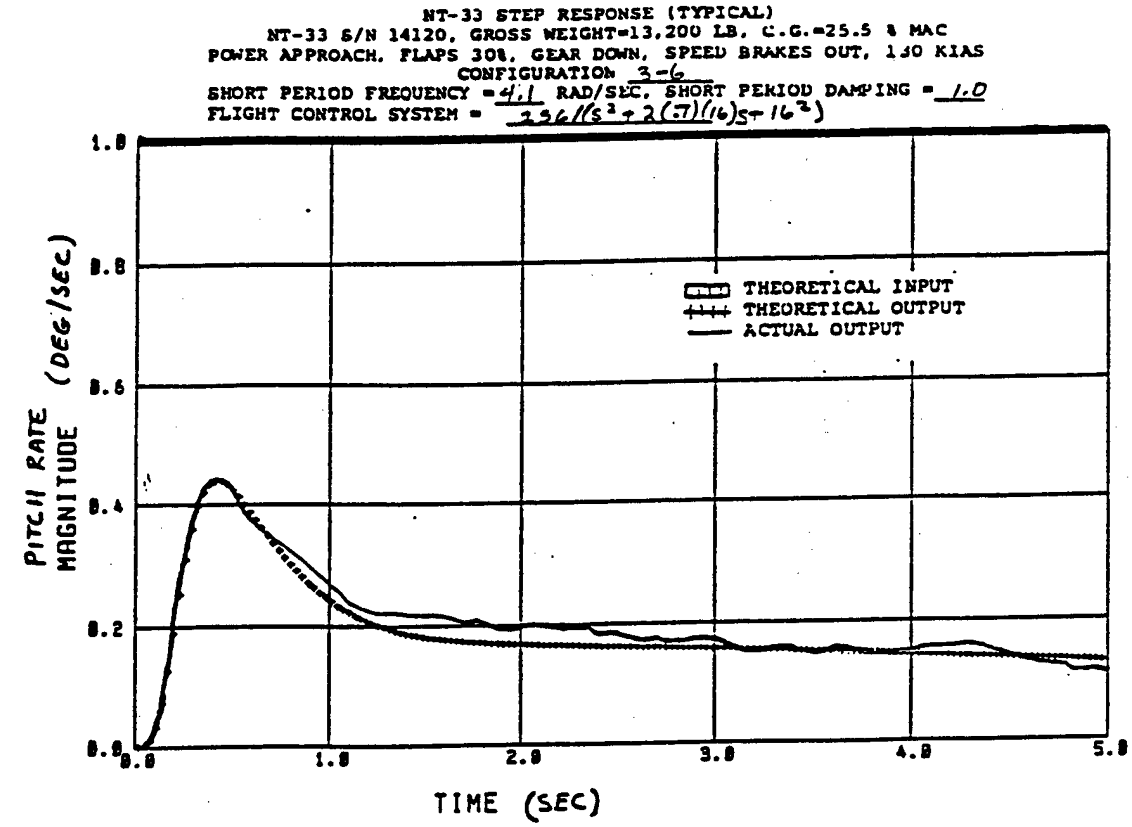

Figure D9. Step Response for Configuration 3-6.

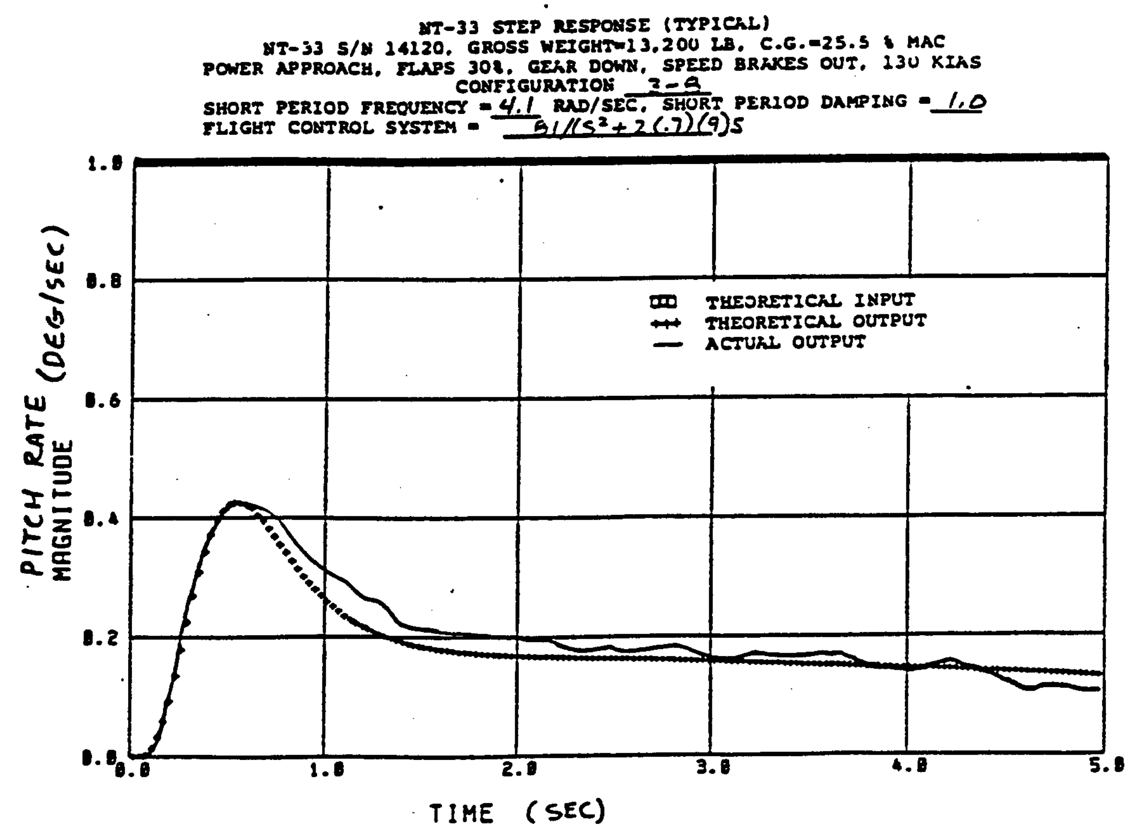

Figure D10. Step Response for Configuration 3-8.

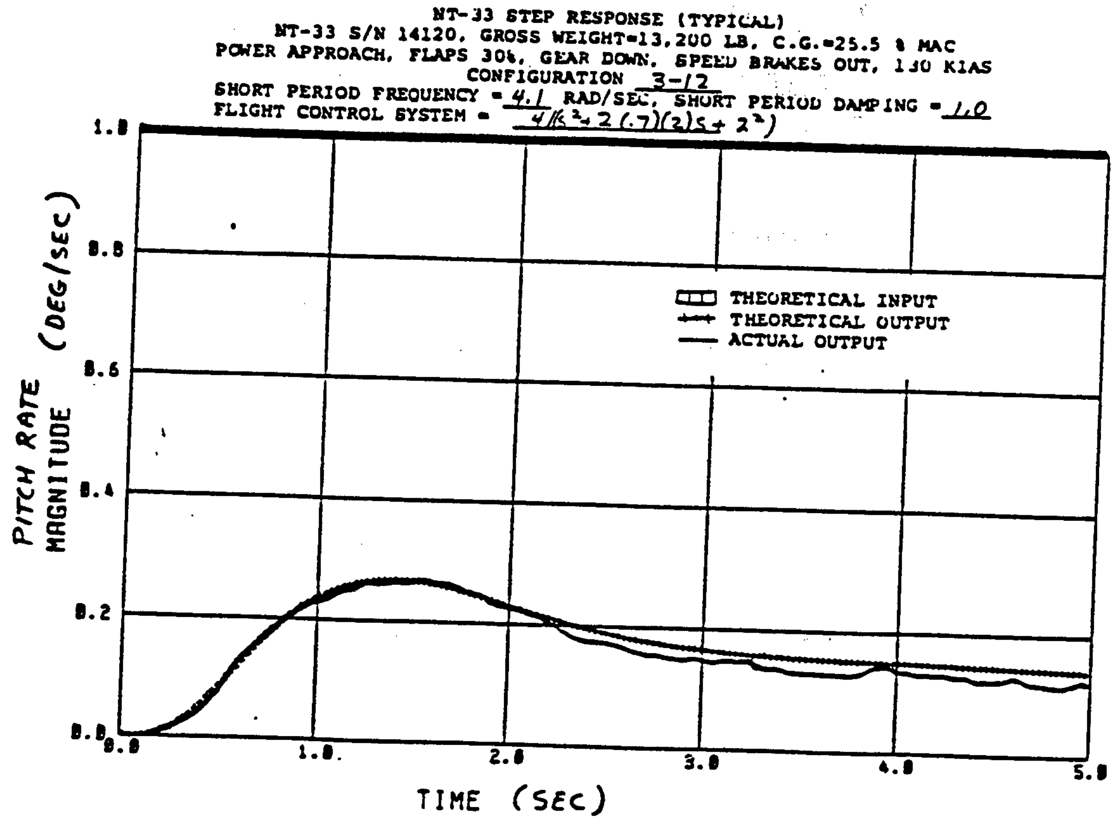

Figure D11. Step Response for Configuration 3-12.

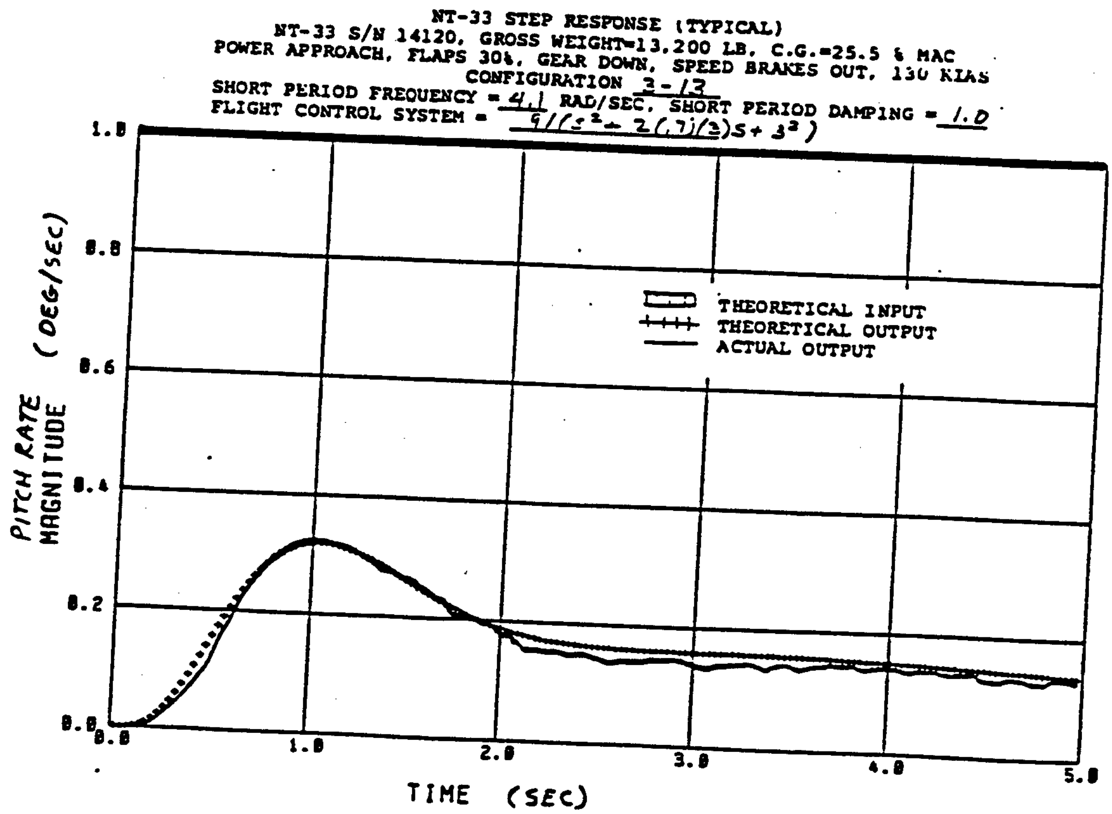

Figure D12. Step Response for Configuration 3-13.

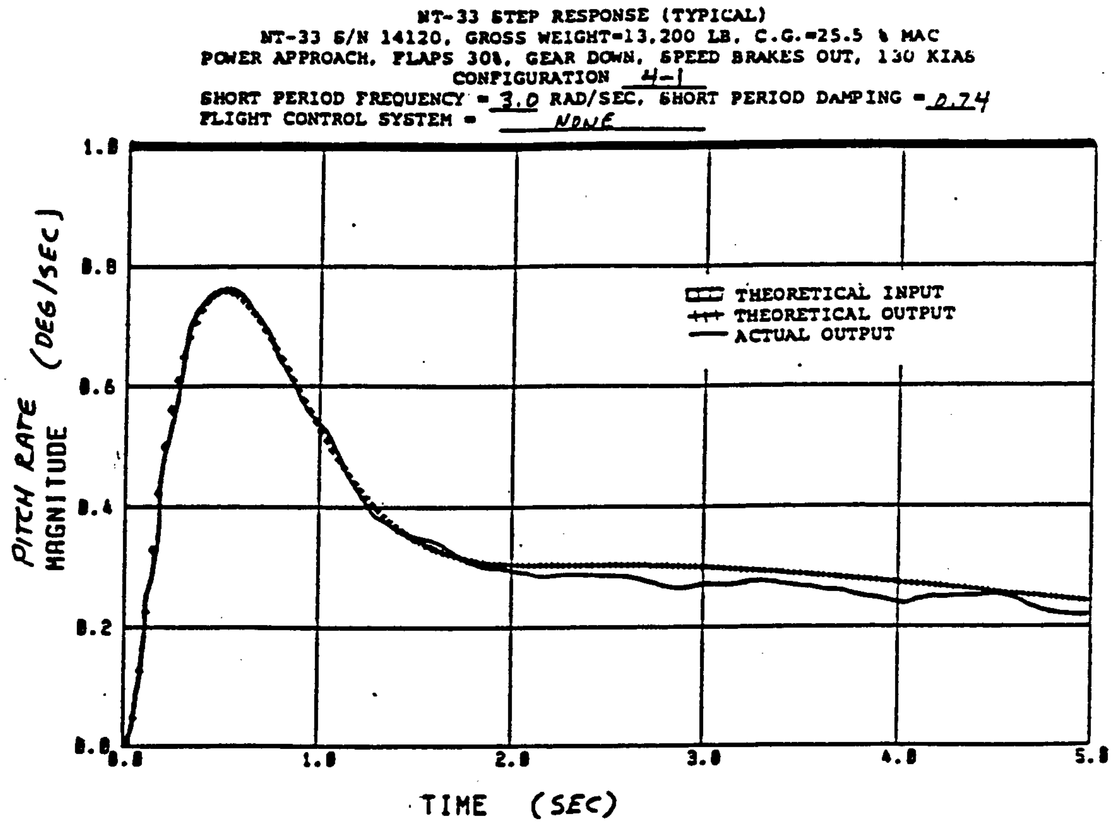

Figure D13. Step Response for Configuration 4-1.

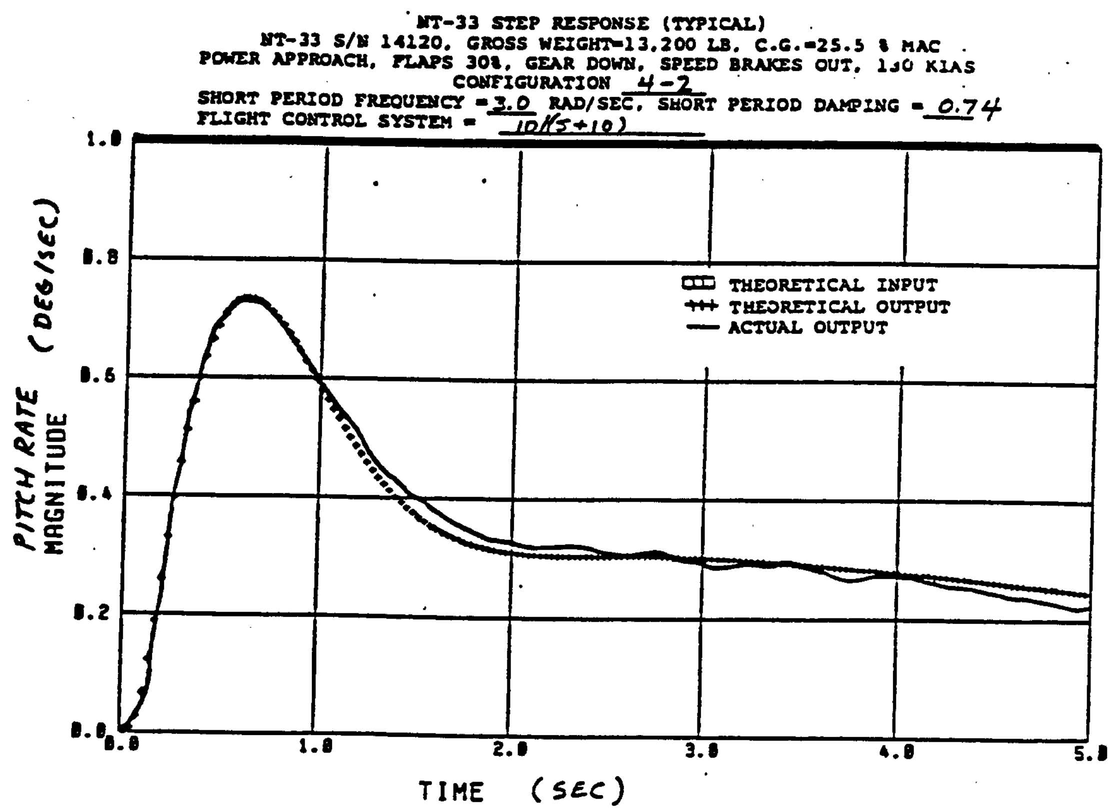

Figure D14. Step Response for Configuration 4-2.

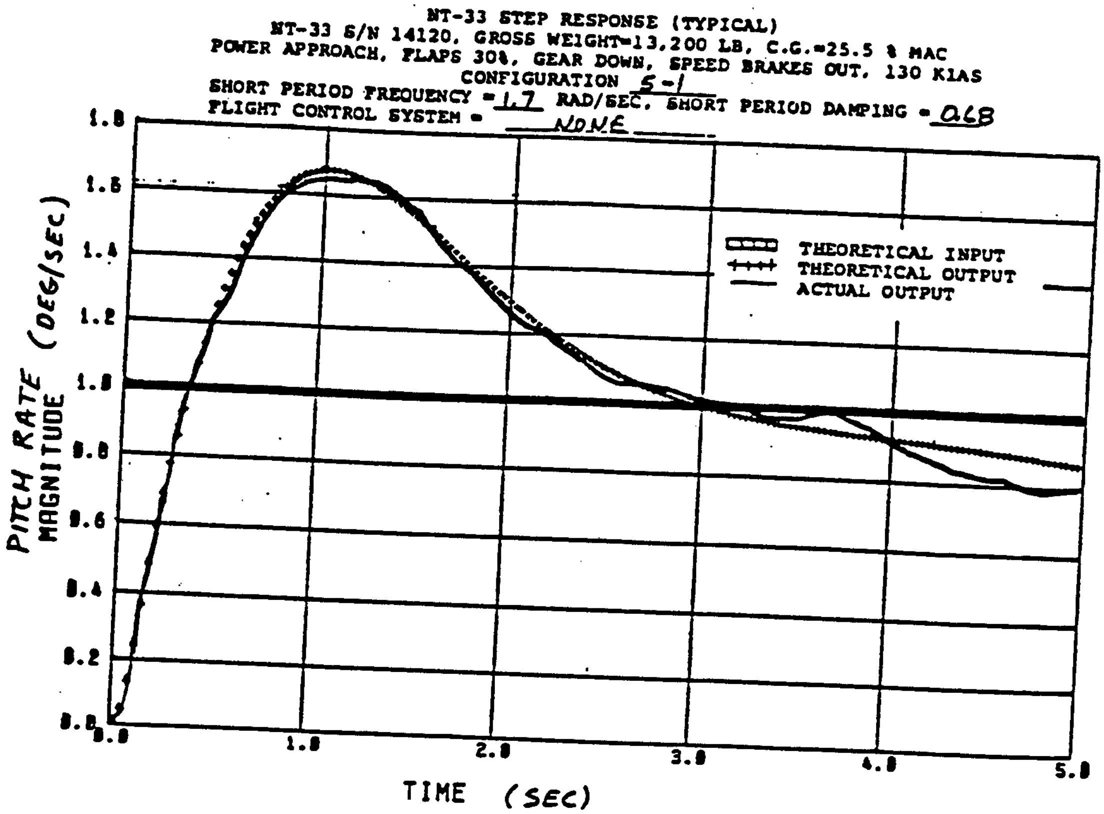

Figure D15. Step Response for Configuration 5-1.

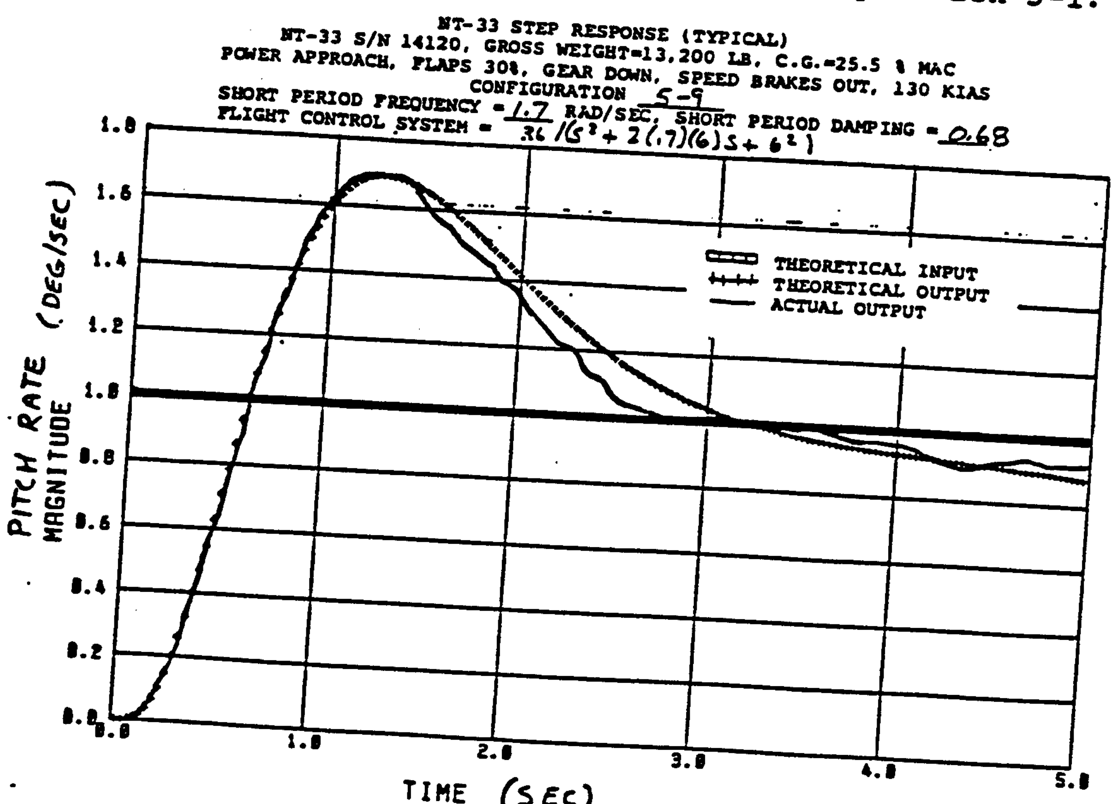

Figure D16. Step Response for Configuration 5-9.

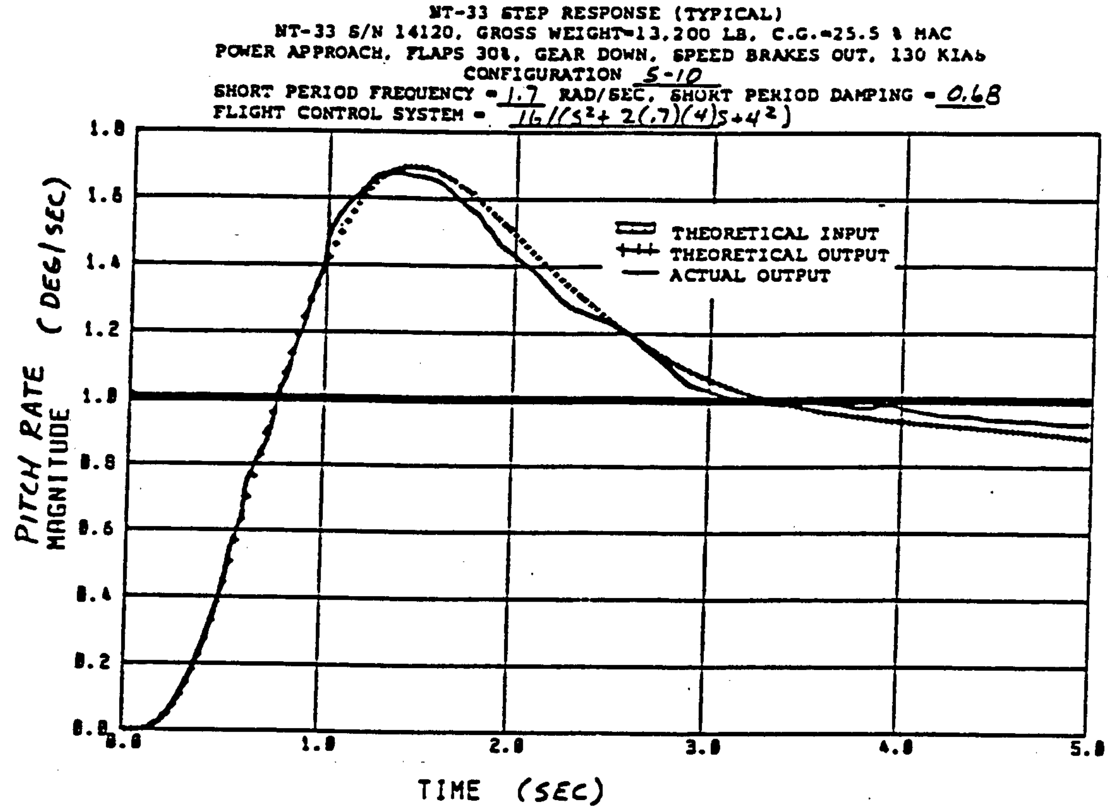

Figure D17. Step Response for Configuration 5-10.

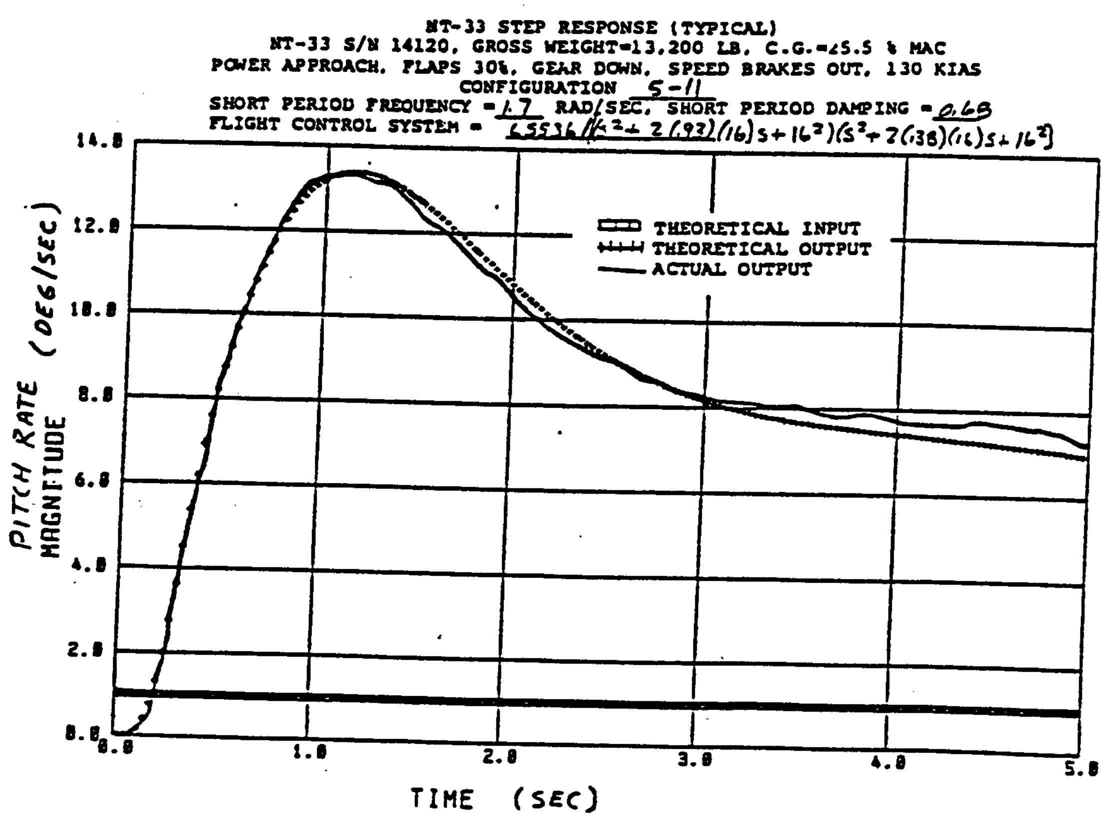

Figure D18. Step Response for Configuration 5-11.

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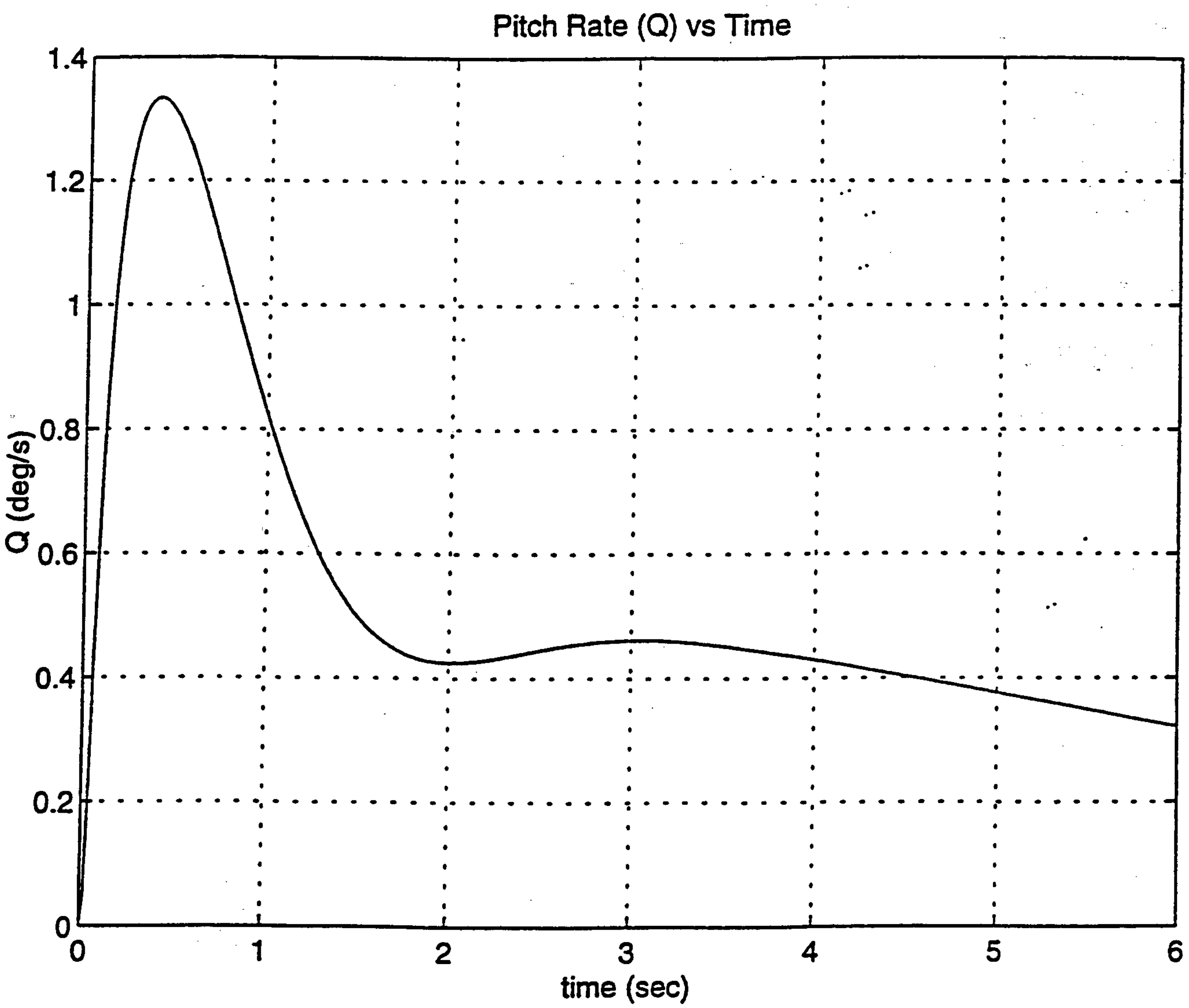
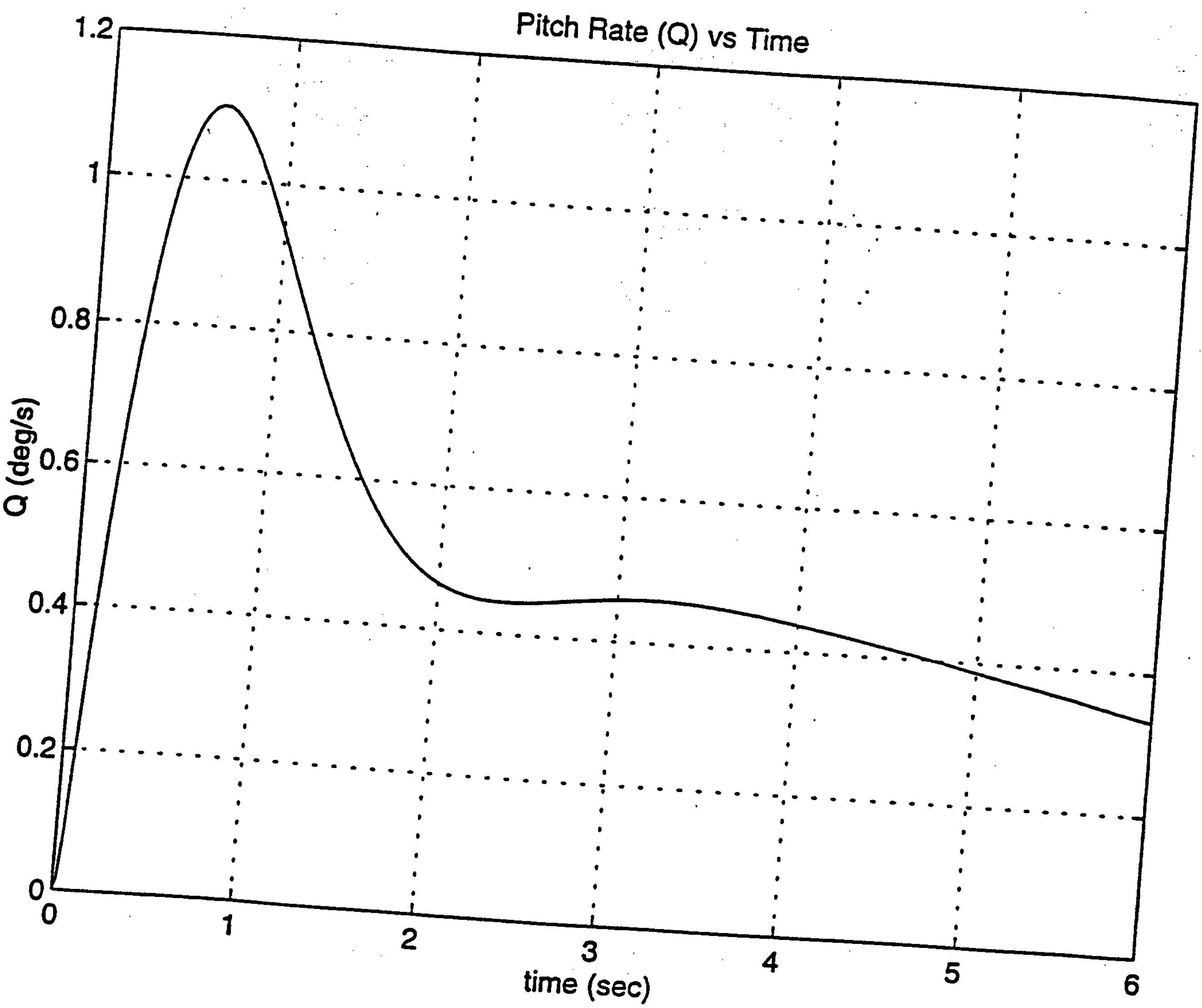
NON-REAL TIME GROUND-BASED SIMULATION MODEL



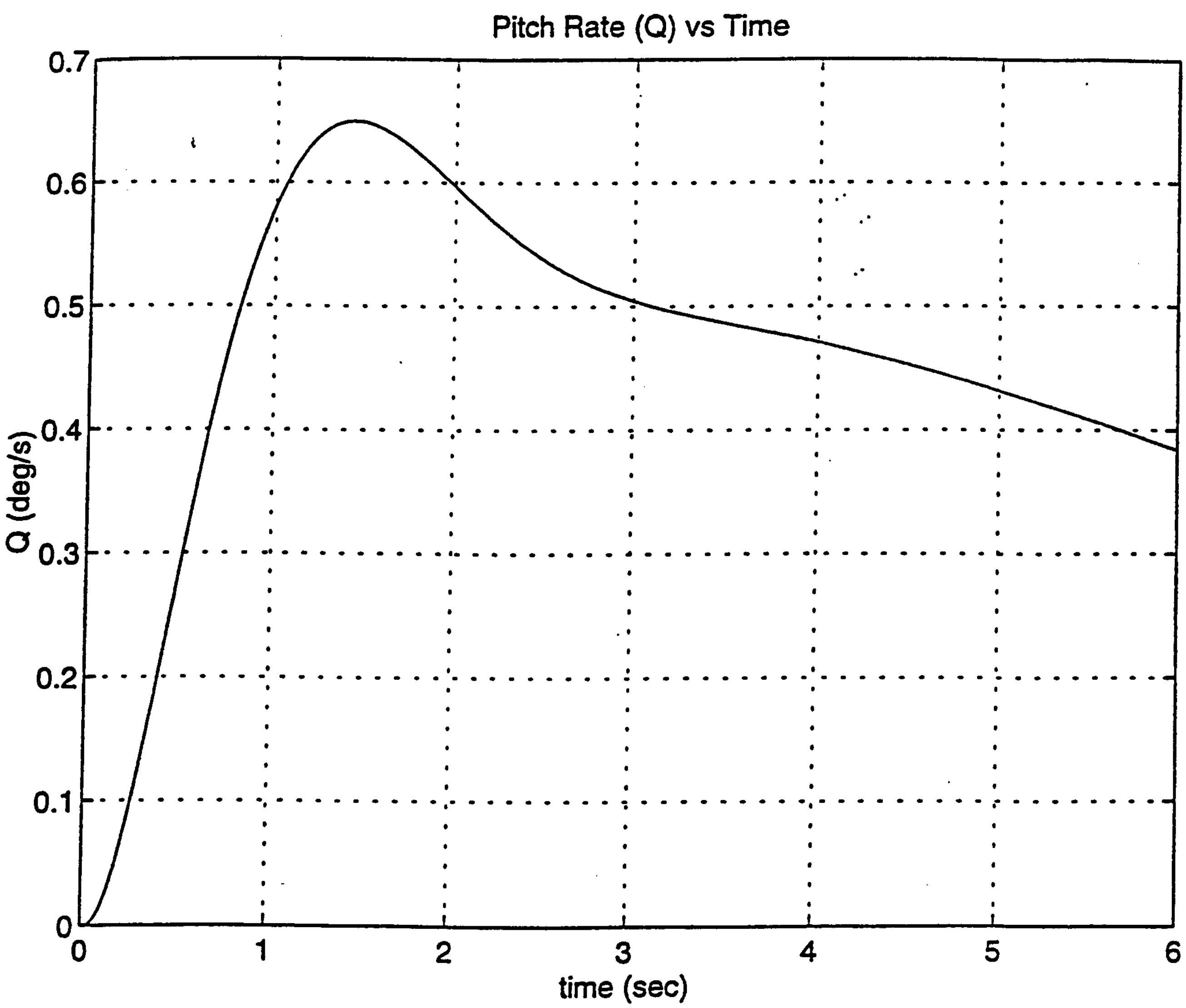
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 2-B

NON-REAL TIME GROUND-BASED SIMULATION MODEL



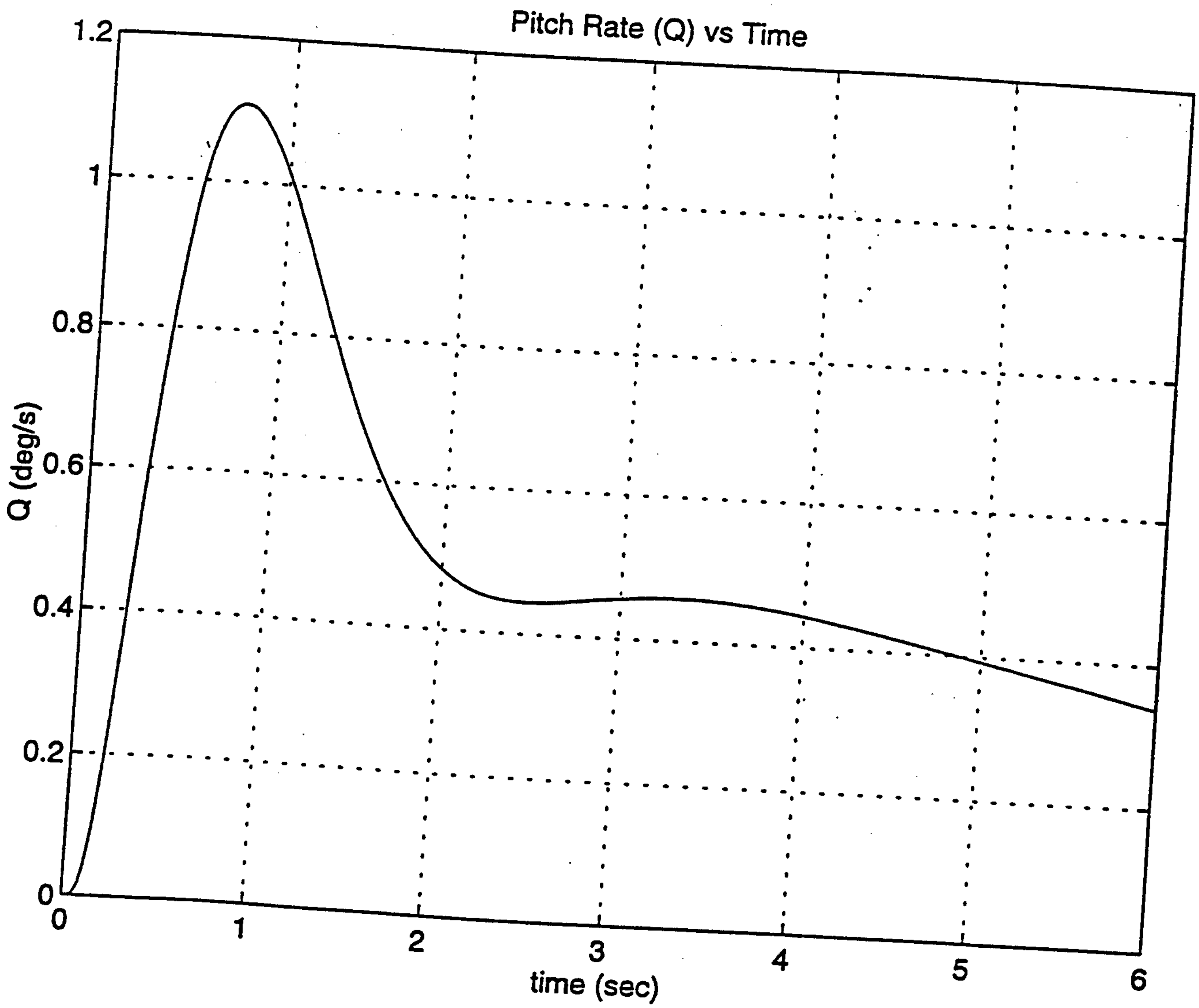
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 2-1

NON-REAL TIME GROUND-BASED SIMULATION MODEL

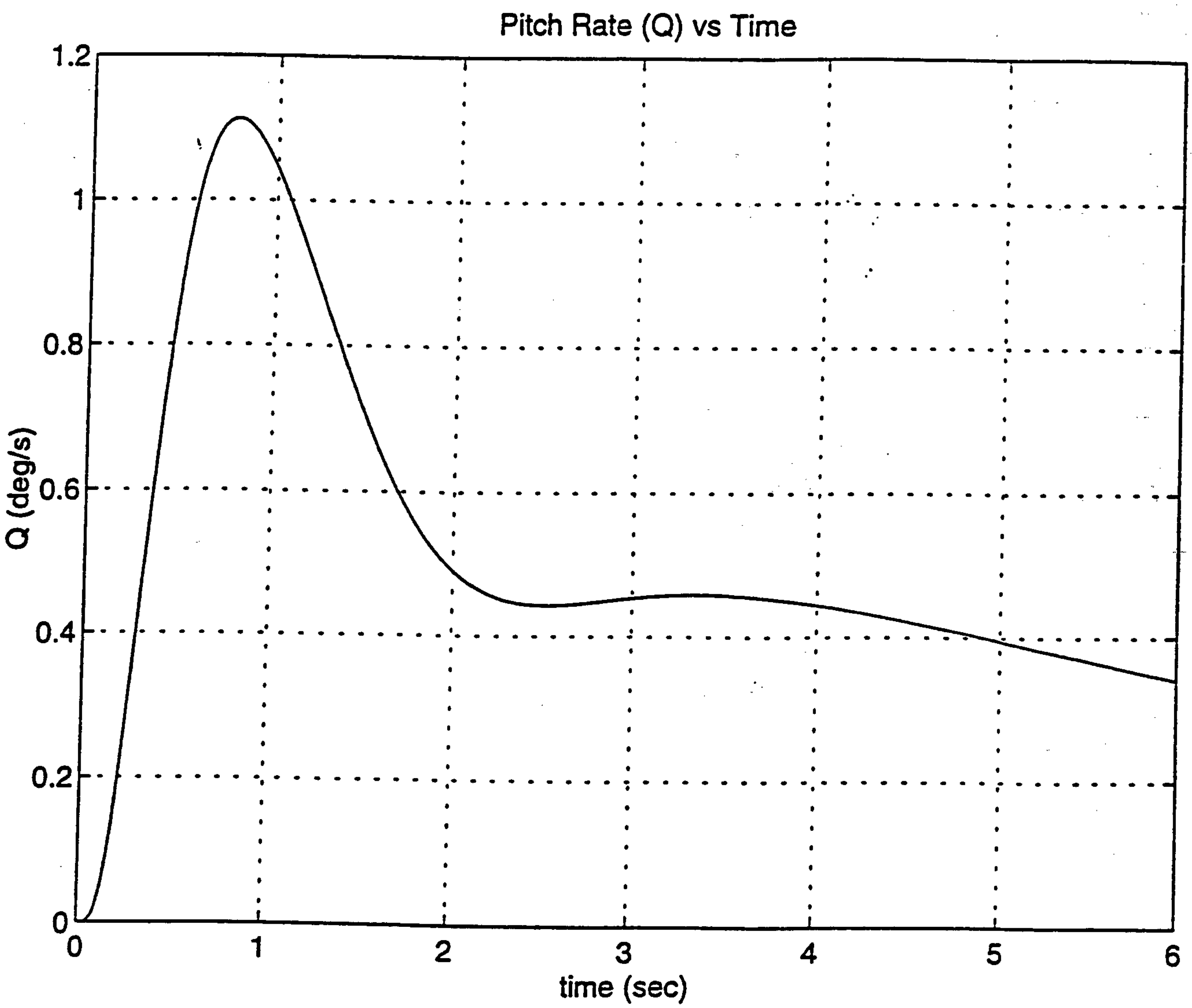


PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 2-5

NON-REAL TIME GROUND-BASED SIMULATION MODEL

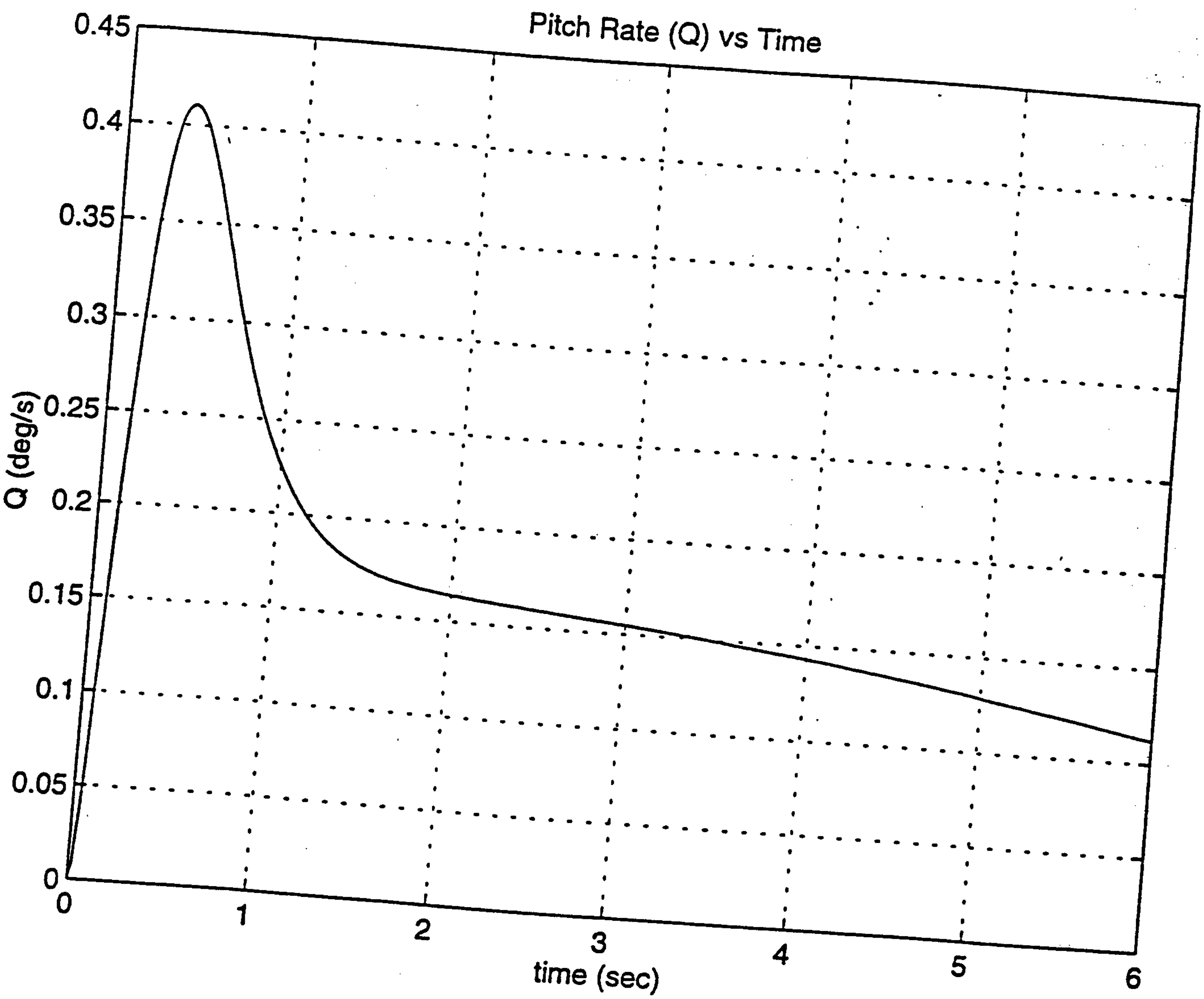


PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 2-7



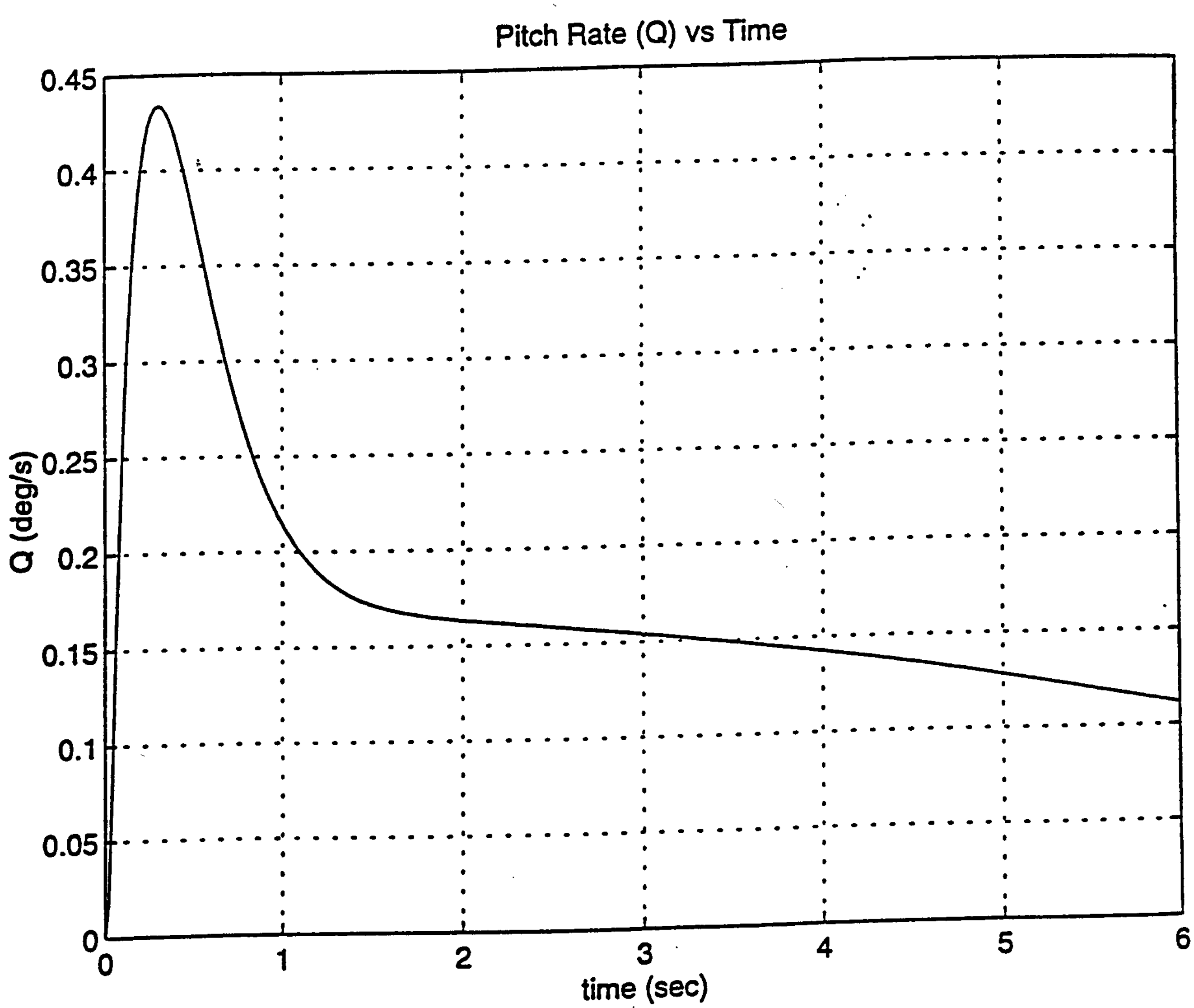
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 2-8

NON-REAL TIME GROUND-BASED SIMULATION MODEL



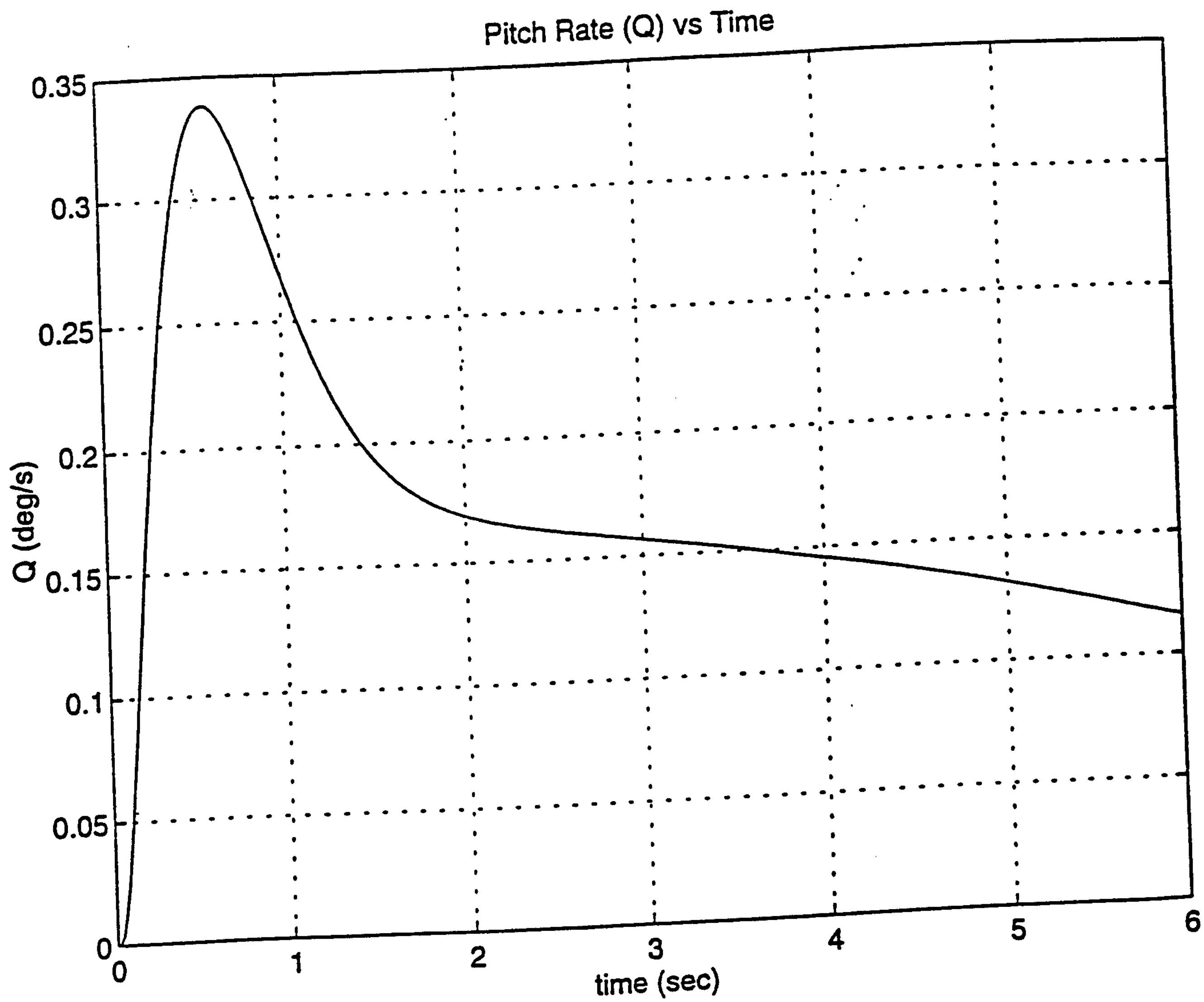
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 3-D

NON-REAL TIME GROUND-BASED SIMULATION MODEL



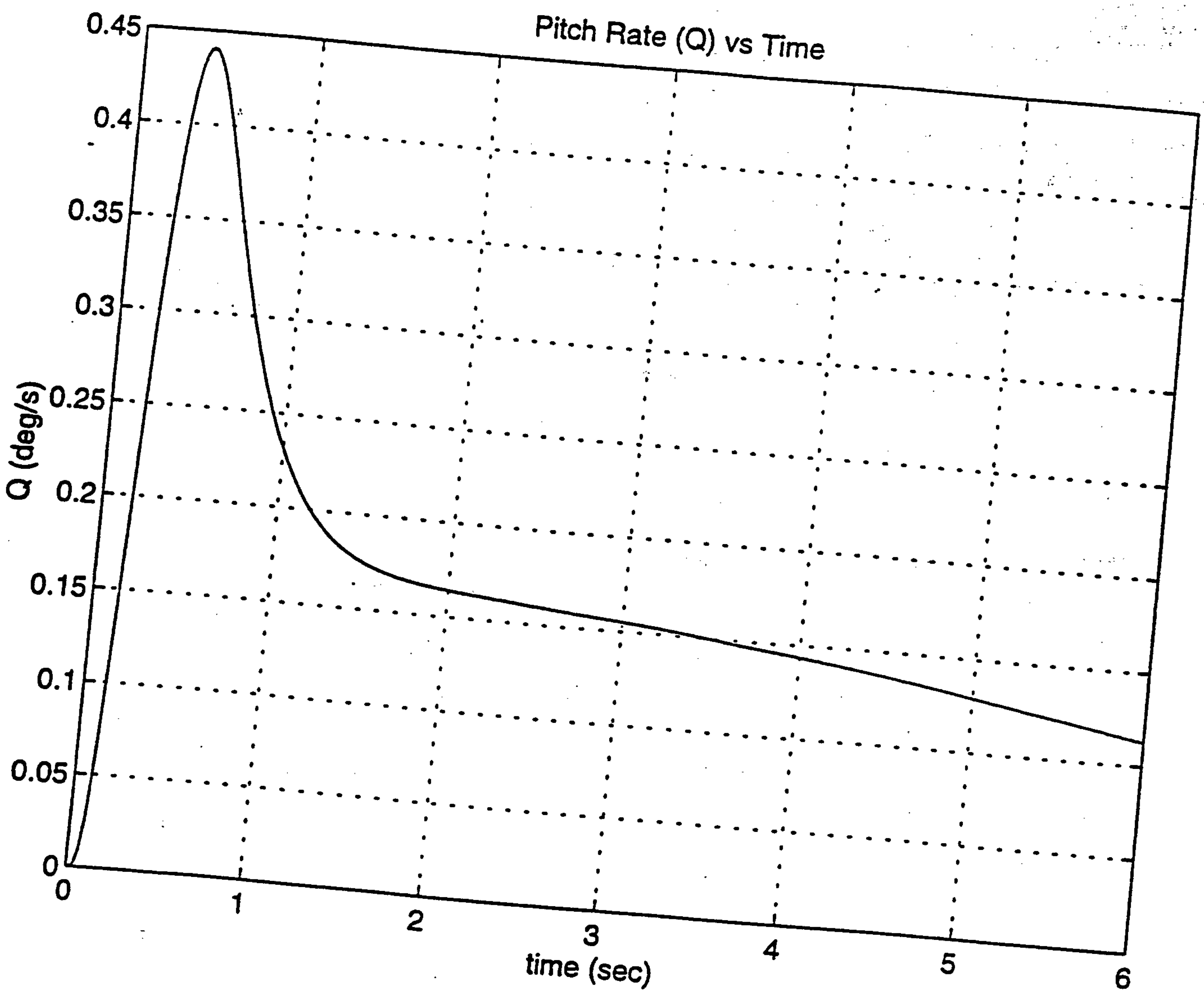
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 3-1

NON-REAL TIME GROUND-BASED SIMULATION MODEL



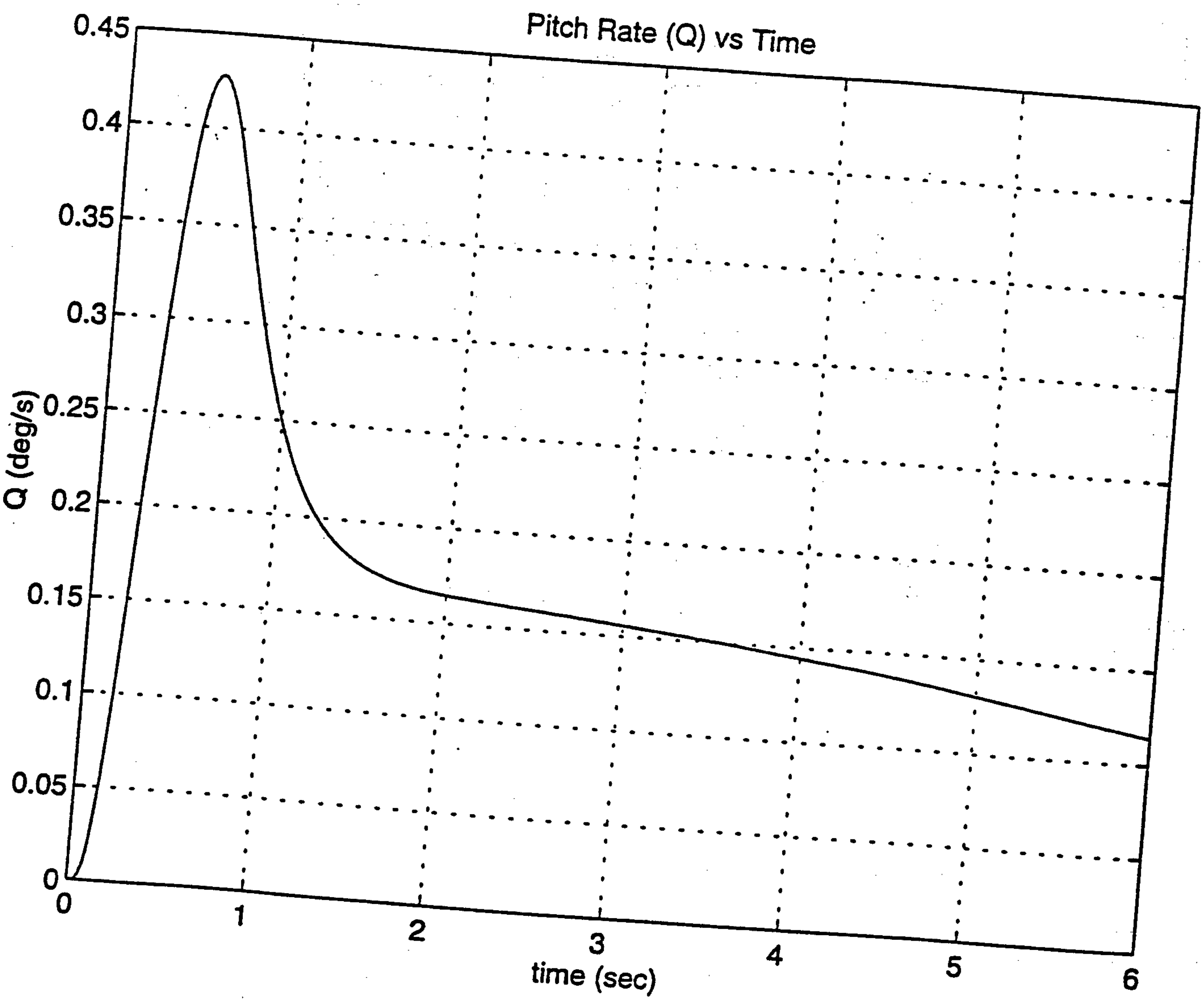
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 3-3

NON-REAL TIME GROUND-BASED SIMULATION MODEL

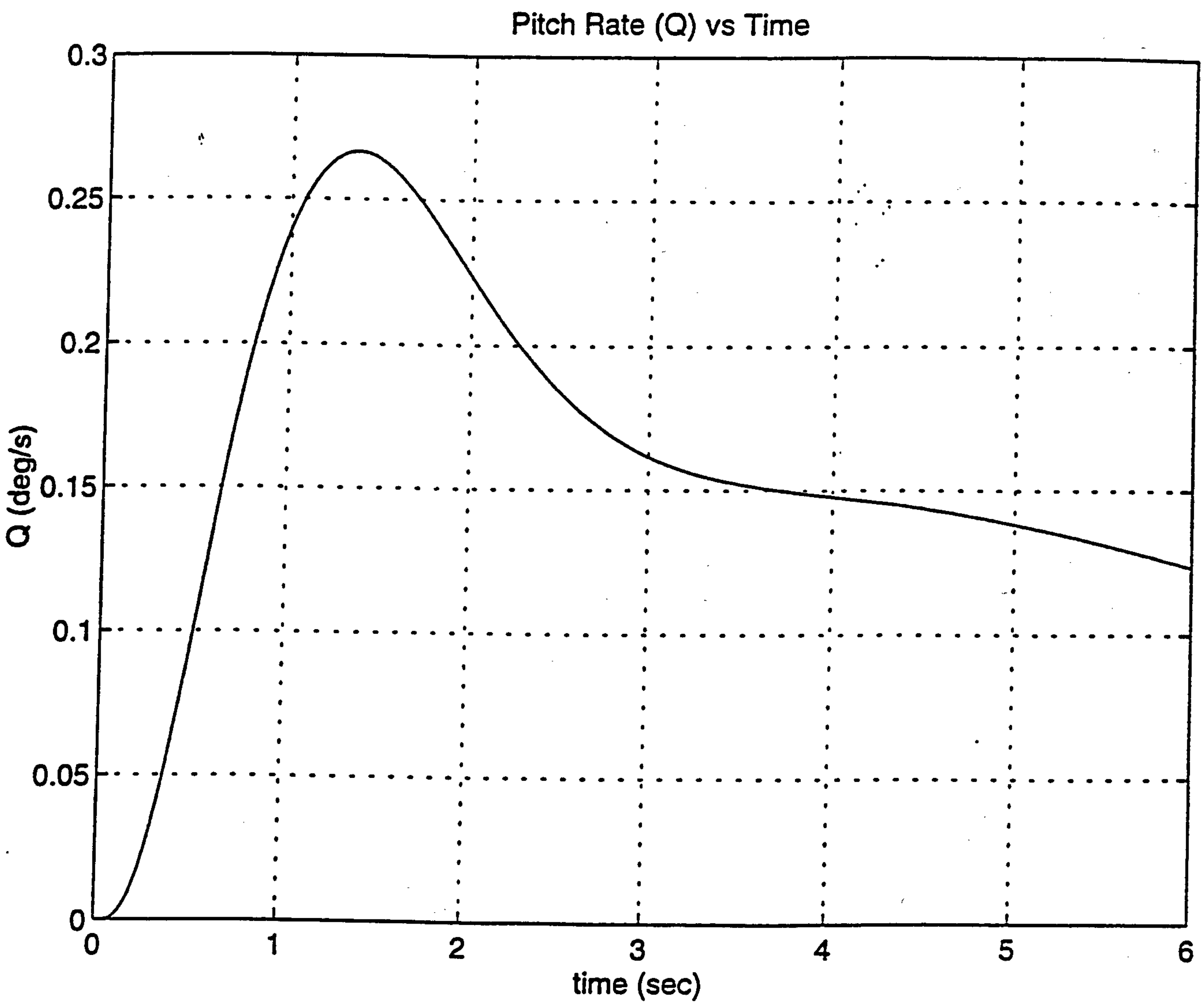


PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 3-6

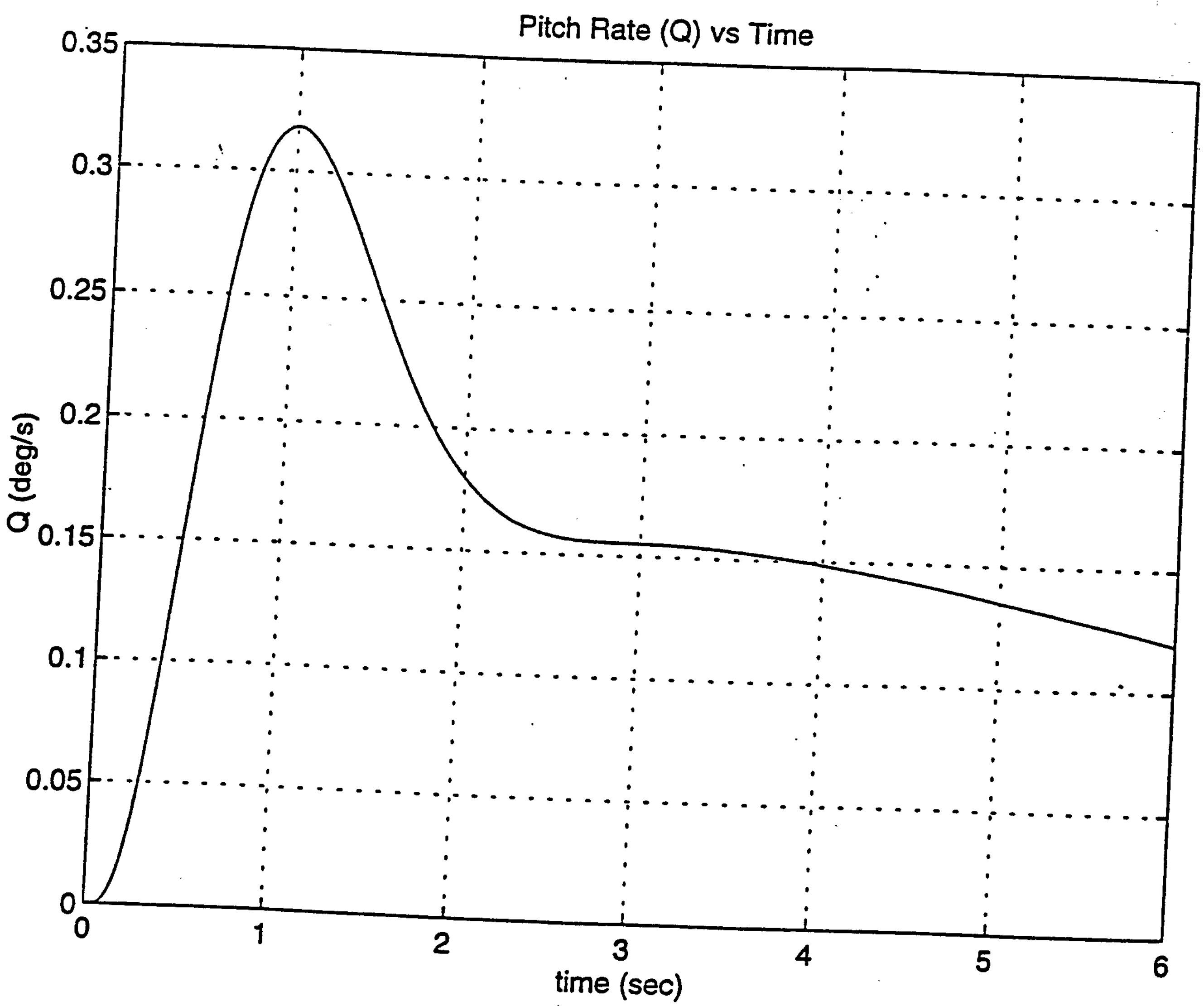
NON-REAL TIME GROUND-BASED SIMULATION MODEL



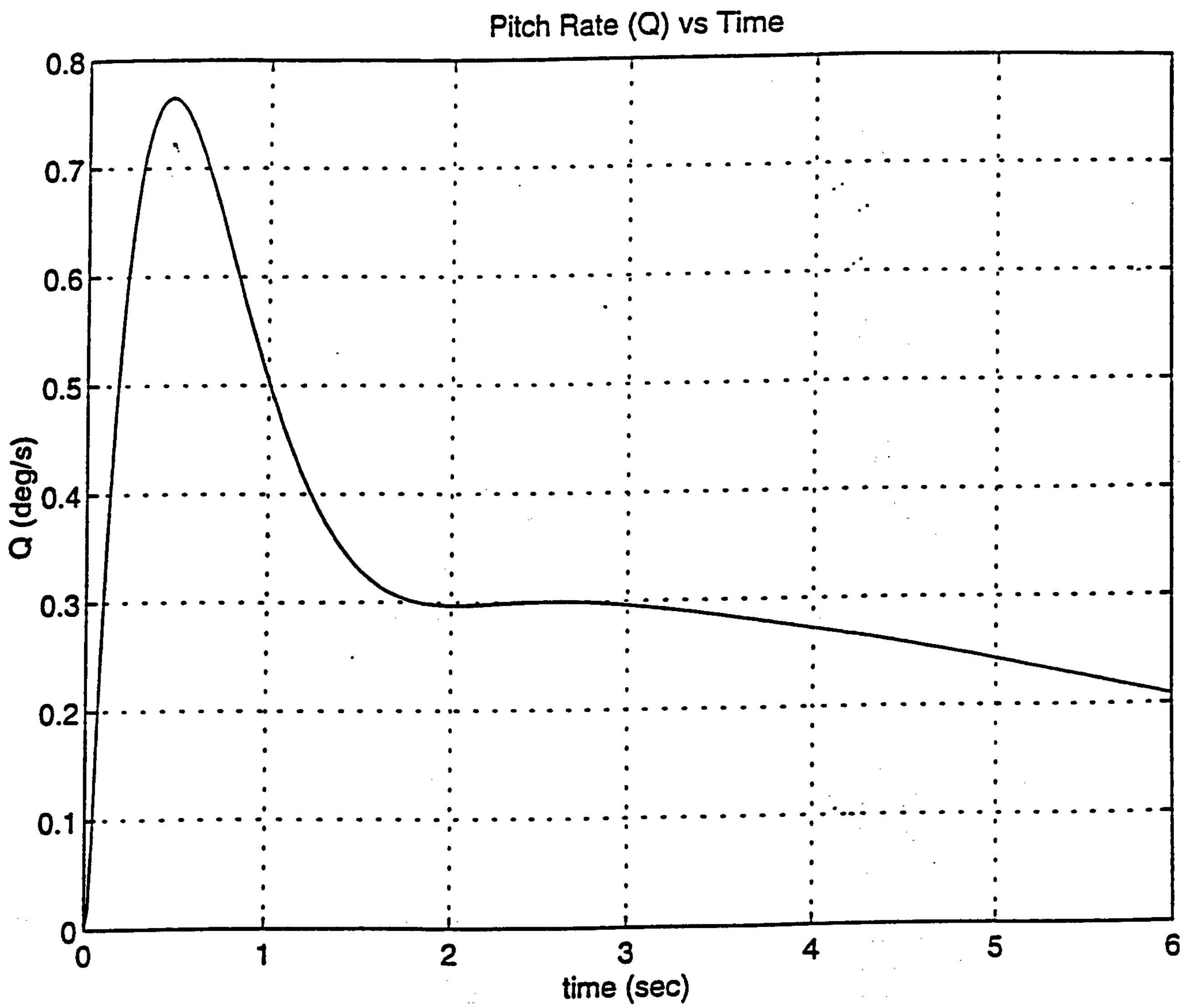
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 3-8



PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 3-12

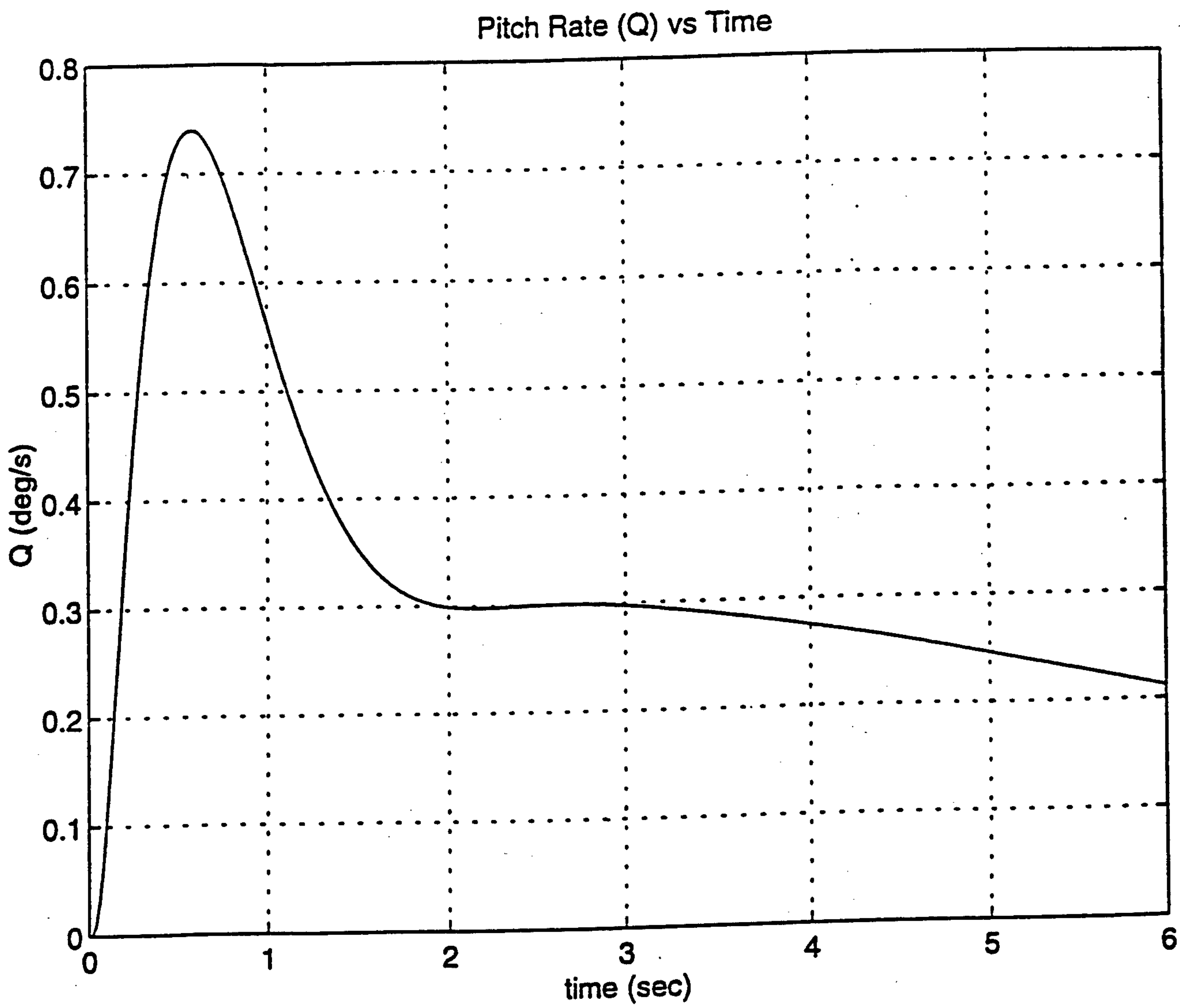


PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 3-13

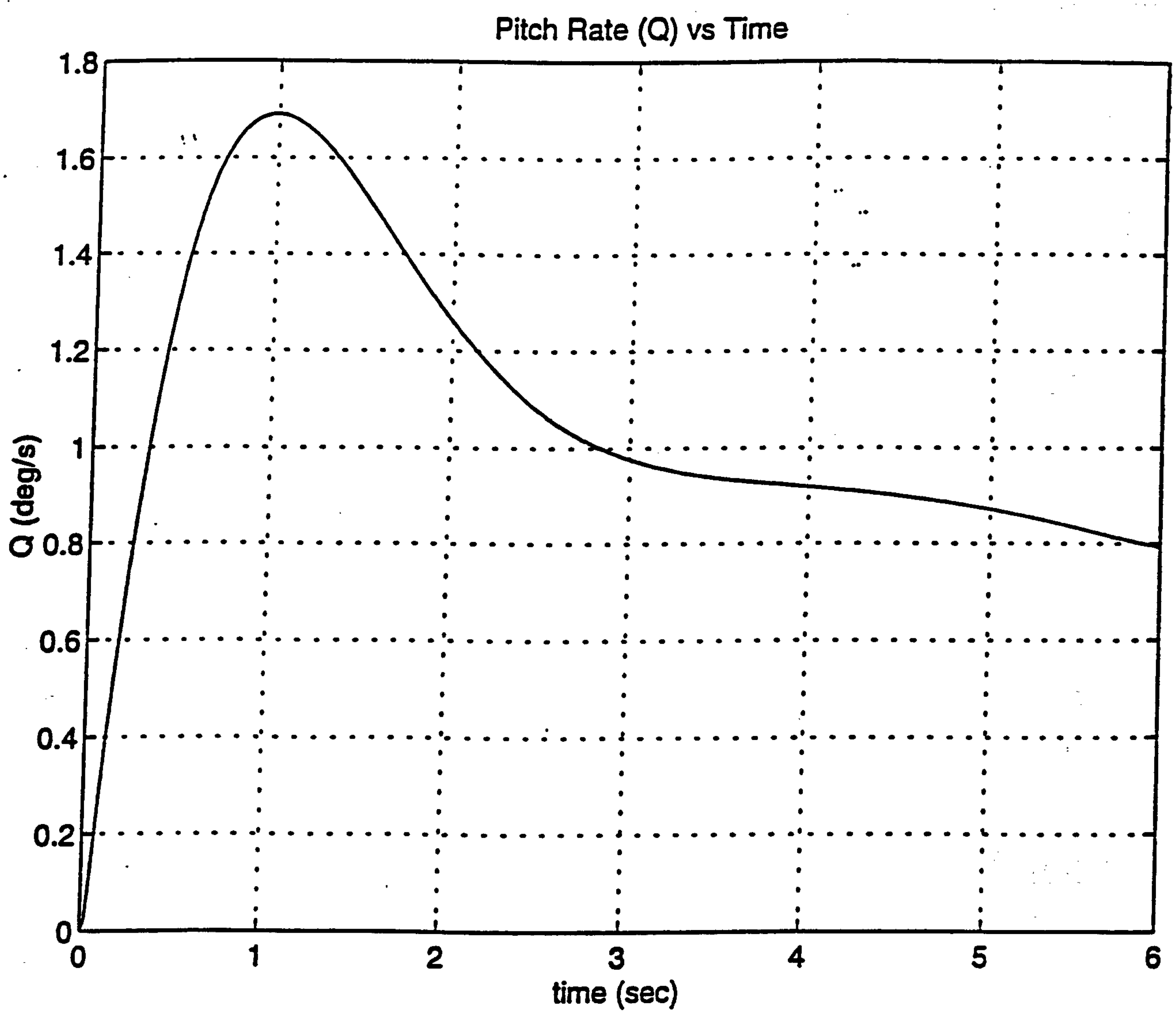


PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 4-1

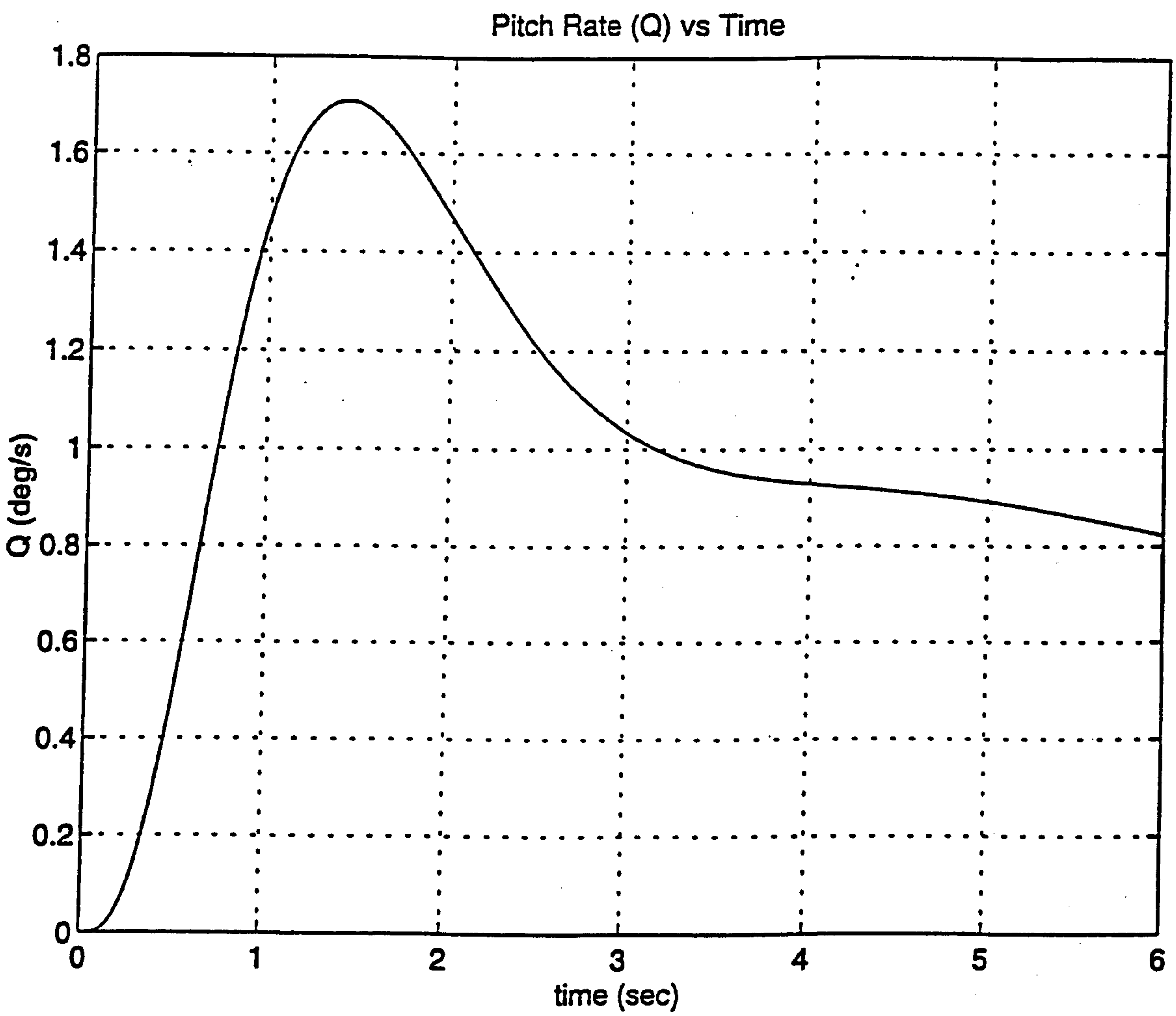
NON-REAL TIME GROUND-BASED SIMULATION MODEL



PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 4-2

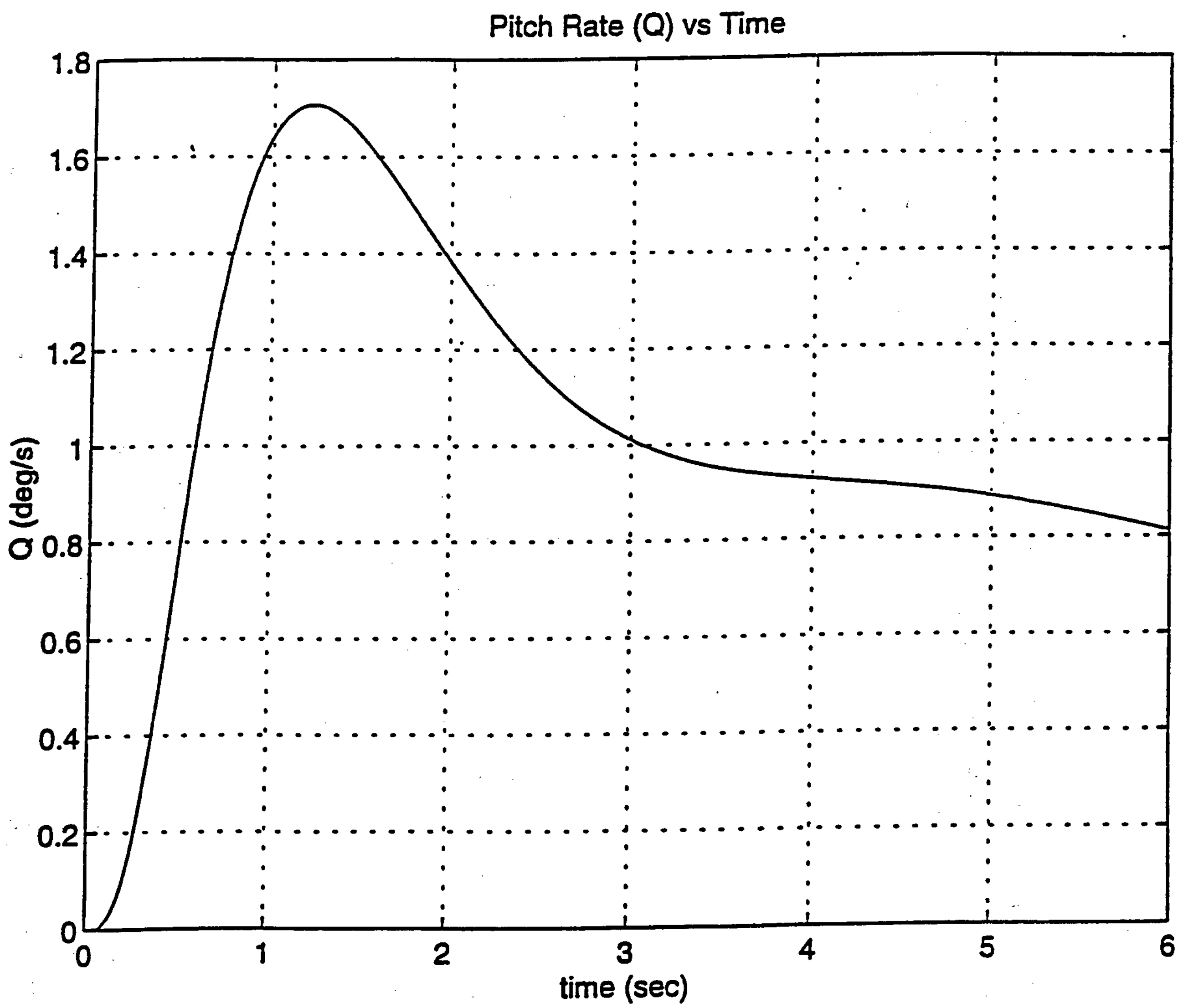


PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 5-1



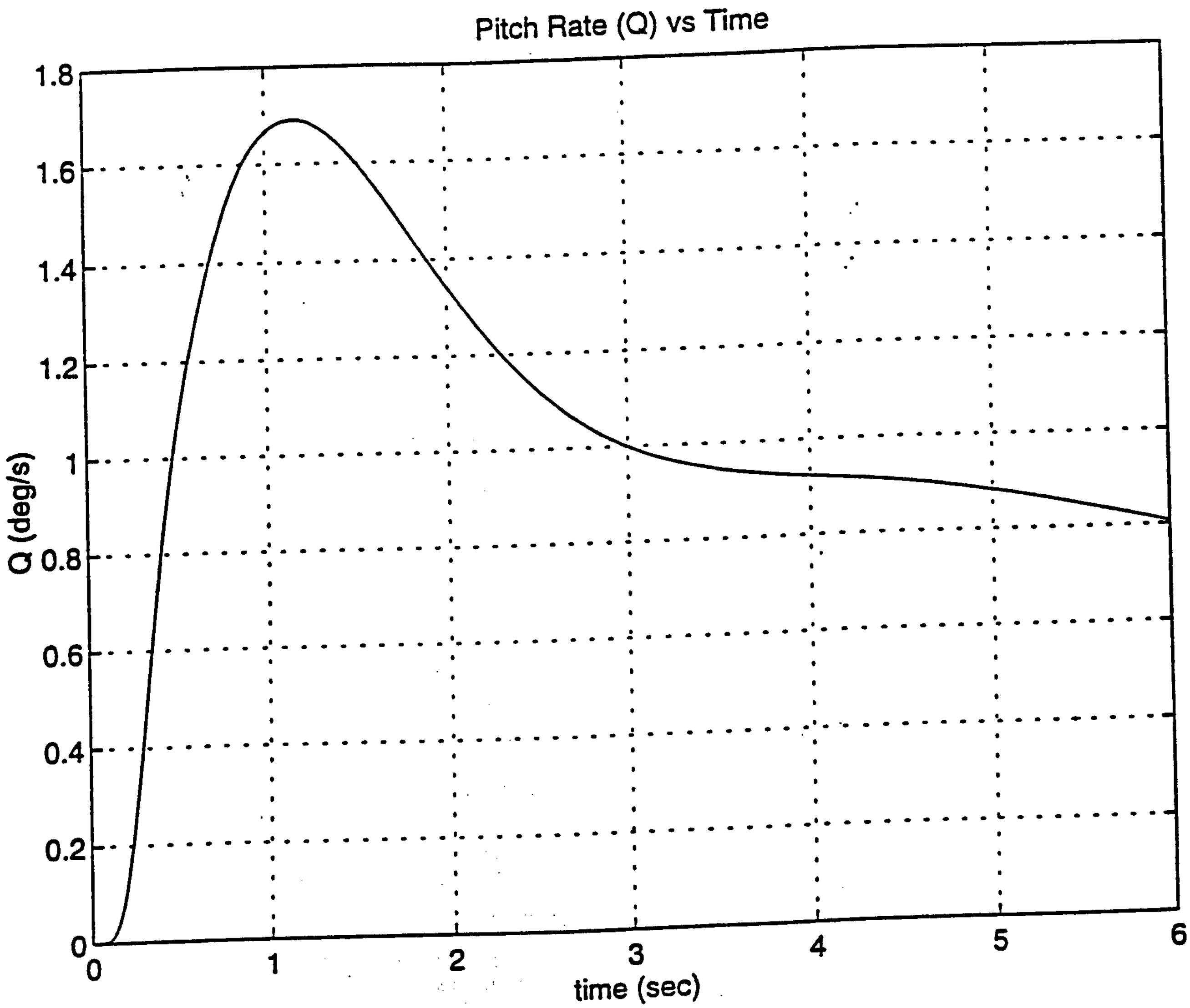
PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 5-10

NON-REAL TIME GROUND-BASED SIMULATION MODEL



PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 5-9

NON-REAL TIME GROUND-BASED SIMULATION MODEL



PITCH RATE RESPONSE WITH STEP INPUT FOR CONFIGURATION 5-11

APPENDIX D

SELECTED PILOT COMMENT CARDS IN GROUND-BASED SIMULATION

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INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY 96 OPS#: ________ PILOT: SASSCER

FLIGHT#: ________ RUN#: 1-3 CONFIG: 3-3

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	FAST
-FINAL RESPONSE?	SLO	MED	FAST
-PREDICTABILITY?	NOT	SAT	EXLNT

-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED? LOW MED HIGH WORKING STICK

-TENDENCY TOWARD PIO? NO LOW MED HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?	DES	ADQ	OFF
-TOUCHDOWN ACCURACY?	DES	ADQ	OVER
-TOUCHDOWN SINK RATE?	LOW	MED	DROP
-RUNWAY ALIGNMENT?	DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?	LOW	MED	HIGH

-SPECIAL CONTROL REQD IN FLARE? NO LOW MED HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ________

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ________ OPS#: ________ PILOT: ________

FLIGHT#: ________ RUN#: ________ CONFIG: ________

ADDITIONAL FACTORS: WINDS ________ / ________

-TURBULENCE? —LT—MED—HVY-

-LAT/DIR PERFORMANCE? SLO MED FAST FINE

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

NONE, NOSE MOVEMENT BUT COULD QUICKLY MOVE IT BACK

- GOOD FEATURES

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

WANTED A 4, BUT WENT TO 5

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ________ PILOT: SASSCER

FLIGHT#: ______ RUN#: 4-7 CONFIG: 3-8

FEEL SYSTEM CHARACTERISTICS:

- -FORCES? LT MED HVY
- -PITCH SENSITIVITY? LOW MED HIGH

PITCH ATTITUDE CONTROL:

- -INITIAL RESPONSE? SLO MED FAST
- -FINAL RESPONSE? SLO MED FAST
- -PREDICTABILITY? NOT SAT EXLNT
- -SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED? LOW MED HIGH
- -TENDENCY TOWARD PIO? NO LOW MED HIGH

TASK PERFORMANCE:

- -AIRSPEED CONTROL? DES ADQ OFF
- -TOUCHDOWN ACCURACY? DES ADQ OVER
- -TOUCHDOWN SINK RATE? LOW MED DROP
- -RUNWAY ALIGNMENT? DES ADQ OVER
- -AGGRESSIVENESS LEVEL? LOW MED HIGH
- -SPECIAL CONTROL REQD IN FLARE? NO LOW MED HIGH
  A LOT OF SMALL STICK MOTION
- -REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ________

INFLIGHT PILOT COMMENT CARD

DATE: ________ OPS#: ________ PILOT: ________

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE? LT MED HVY

-LAT/DIR PERFORMANCE? SLO MED FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS
  OSCILLATION, REALLY HAD TO WORK K

- GOOD FEATURES
  RESPONDED QUICKLY

REVIEW RATINGS:

- -PIO? 1 2 3 4 5 6
- -COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 8-10 CONFIG: 4-1

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?		SLO	MED	FAST
-FINAL RESPONSE?		SLO	MED	FAST
-PREDICTABILITY?		NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?		LOW	MED	HIGH
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

NONE

- GOOD FEATURES

PUT A/C WHERE HE WANTED,

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 11-13 CONFIG: 2-7

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	FAST
-FINAL RESPONSE?	SLO	MED	FAST
-PREDICTABILITY?	NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?	LOW	MED	HIGH
-TENDENCY TOWARD PIO?	NO	LOW MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?	LOW		MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

  FELT IT COULD GET AWAY FROM IT NOSE WOULD OSCILLATE, BUT ALWAYS CAUGHT IT.

- GOOD FEATURES

  OSCILLATION DAMPS W/COMPENS

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ________ PILOT: SASSCER

FLIGHT#: ________ RUN#: 14-16 CONFIG: 2-5

FEEL SYSTEM CHARACTERISTICS:

-FORCES? LT MED HVY

-PITCH SENSITIVITY? LOW MED HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE? SLO MED FAST

-FINAL RESPONSE? SLO MED FAST

-PREDICTABILITY? NOT SAT EXLNT

-SPECIAL PILOT TECHNIQUES/
COMPENSATION REQUIRED? LOW MED HIGH

-TENDENCY TOWARD PIO? NO LOW MED HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL? DES ADQ OFF

-TOUCHDOWN ACCURACY? DES ADQ OVER

-TOUCHDOWN SINK RATE? LOW MED DROP

-RUNWAY ALIGNMENT? DES ADQ OVER

-AGGRESSIVENESS LEVEL? LOW MED HIGH

-SPECIAL CONTROL REQD
IN FLARE? NO LOW MED HIGH

-REASON APPROACH ABANDONED
HANDLING QUAL OR PIO? ________

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ________ OPS#: ________ PILOT: ________

FLIGHT#: ________ RUN#: ________ CONFIG: ________

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE? LT MED HVY

-LAT/DIR PERFORMANCE? SLO MED FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS
SLUGGISHNESS. HARD TO MOVE, THEN STOP IT WHERE HE WANTED

- GOOD FEATURES
STABLE

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 17-19 CONFIG: 3-6

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?		SLO	MED	FAST
-FINAL RESPONSE?		SLO	MED	FAST
-PREDICTABILITY?		NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?		LOW	MED	HIGH
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

OSCILLATION

- GOOD FEATURES

SENSITIVE, STICK MOVES SO DOES NOSE

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ________ PILOT: SASSCER

FLIGHT#: ________ RUN#: 20-22 CONFIG: 2-8

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?		SLO	MED	FAST
-FINAL RESPONSE?		SLO	MED	FAST
-PREDICTABILITY?		NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?		LOW	MED	HIGH
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

WORKING STICK HARD

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ________________

INFLIGHT PILOT COMMENT CARD cont.

DATE: ________ OPS#: ________ PILOT: ________

FLIGHT#: ________ RUN#: ________ CONFIG: ________

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

QUICK RESPONSE OF NOSE

- GOOD FEATURES

DIDN'T OSCILLATE

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 23-25 CONFIG: 4-2

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	FAST
-FINAL RESPONSE?	SLO	MED	FAST
-PREDICTABILITY?	NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?	LOW	MED	HIGH

-TENDENCY TOWARD PIO? NO LOW MED HIGH

OPEN-LOOP OSCILLATION

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

MINOR - OPEN-LOOP OSCILLATION
QUICK SMALL STICK MOVEMENTS AS COMPENSATION

- GOOD FEATURES

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY 96 OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 26-28 CONFIG: 5-11

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	FAST
-FINAL RESPONSE?	SLO	MED	FAST
-PREDICTABILITY?	NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?	LOW	MED	HIGH

-TENDENCY TOWARD PIO? NO LOW MED HIGH
WAS MOVEMENT

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

LARGE NOSE MOVEMENTS MADE IT HARD TO CONTROL SINK RATE

- GOOD FEATURES

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 29-31 CONFIG: 2-1

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?		SLO	MED	FAST
-FINAL RESPONSE?		SLO	MED	FAST
-PREDICTABILITY?		NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?		LOW	MED	HIGH
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

OSCILLATIONS, A LOT OF WORK TO OVERCOME.

- GOOD FEATURES

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ____ PILOT: SASSCER

FLIGHT#: ____ RUN#: 32-34 CONFIG: 5-10

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?		SLO	MED	FAST
-FINAL RESPONSE?		SLO	MED	FAST
-PREDICTABILITY?		NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?		LOW	MED	VERY HIGH
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	VERY HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? PIO

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ____ OPS#: ____ PILOT: ____

FLIGHT#: ____ RUN#: ____ CONFIG: ____

ADDITIONAL FACTORS: WINDS ____ / ____

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

PIO, COULDN'T BRING UNDER

- GOOD FEATURES

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ± 250 FT. APPROACH AIRSPEED ± 5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ± 500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 35-37 CONFIG: 2-B

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	FAST	
-FINAL RESPONSE?	SLO	MED	FAST	
-PREDICTABILITY?	NOT	SAT	EXLNT	
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?	LOW	MED	HIGH	
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?	DES	ADQ	OFF	
-TOUCHDOWN ACCURACY?	DES	ADQ	OVER	
-TOUCHDOWN SINK RATE?	LOW	MED	DROP	
-RUNWAY ALIGNMENT?	DES	ADQ	OVER	
-AGGRESSIVENESS LEVEL?	LOW	MED	HIGH	
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

QUICK OSCILLATION TO A LOT OF COMPENSATION TO CONTROL

- GOOD FEATURES

QUICK RESPONSE

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 38-41 CONFIG: 3-12

FEEL SYSTEM CHARACTERISTICS:

- -FORCES? LT **MED** HVY
- -PITCH SENSITIVITY? **LOW** MED HIGH

PITCH ATTITUDE CONTROL:

- -INITIAL RESPONSE? **SLO** MED FAST
- -FINAL RESPONSE? **SLO** MED FAST
- -PREDICTABILITY? NOT **SAT** EXLNT
- -SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED? LOW **MED** HIGH
- -TENDENCY TOWARD PIO? NO **LOW** MED HIGH

TASK PERFORMANCE:

- -AIRSPEED CONTROL? **DES** ADQ OFF
- -TOUCHDOWN ACCURACY? DES **ADQ** OVER
- -TOUCHDOWN SINK RATE? LOW **MED** DROP
- -RUNWAY ALIGNMENT? **DES** ADQ OVER
- -AGGRESSIVENESS LEVEL? LOW **MED** HIGH
- -SPECIAL CONTROL REQD IN FLARE? NO LOW **MED** HIGH
- -REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

LONG ON ONE, GOT TOO SLOW

INFLIGHT PILOT COMMENT CARD (CONT.)

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

- TURBULENCE? LT MED HVY
- -LAT/DIR PERFORMANCE? SLO **MED** FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

  SLUGGISH NOSE MOTION, HARD TO CONTROL

- GOOD FEATURES

REVIEW RATINGS:

- -PIO? 1 2 **3** 4 5 6
- -COOPER-HARPER? 1 2 3 4 5 6 **7** 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 42-44 CONFIG: 3-D

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	EXTREMELY FAST
-FINAL RESPONSE?	SLO	MED	FAST
-PREDICTABILITY?	NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?	LOW	MED	HIGH

-TENDENCY TOWARD PIO?	NO	VERY LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

BOBBLE AFTER NOSE MOVEMENT.

- GOOD FEATURES

VERY RESPONSIVE IN PITCH.

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

GOOD 5

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT $\pm$250 FT. APPROACH AIRSPEED $\pm$5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT $\pm$500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 45-48 CONFIG: 3-1

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?		SLO	MED	FAST
-FINAL RESPONSE?		SLO	MED	FAST
-PREDICTABILITY?		NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?		LOW	MED	HIGH
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

NONE, LITTLE BUBBLE BUT QUICK RESPONSE. PREDICTABLE

- GOOD FEATURES

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 49-51 CONFIG: 3-13

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	FAST	
-FINAL RESPONSE?	SLO	MED	FAST	
-PREDICTABILITY?	NOT	SAT	EXLNT	
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?	LOW	MED	HIGH	
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

WANDERING

TASK PERFORMANCE:

-AIRSPEED CONTROL?	DES	ADQ	OFF	
-TOUCHDOWN ACCURACY?	DES	ADQ	OVER	
-TOUCHDOWN SINK RATE?	LOW	MED	DROP	
-RUNWAY ALIGNMENT?	DES	ADQ	OVER	
-AGGRESSIVENESS LEVEL?	LOW	MED	HIGH	
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

NONE

MINOR NOSE WANDER

- GOOD FEATURES

CONTROLLABLE.

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTERLINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ________ PILOT: SASSCER

FLIGHT#: ______ RUN#: 52-55 CONFIG: 5-1

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?	SLO	MED	FAST	
-FINAL RESPONSE?	SLO	MED	FAST	
-PREDICTABILITY?	NOT	SAT	EXLNT	
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?	LOW	MED	HIGH	
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?	DES	ADQ	OFF	
-TOUCHDOWN ACCURACY?	DES	ADQ	OVER	
-TOUCHDOWN SINK RATE?	LOW	MED	DROP	
-RUNWAY ALIGNMENT?	DES	ADQ	OVER	
-AGGRESSIVENESS LEVEL?	LOW	MED	HIGH	
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ____________

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ________ OPS#: ________ PILOT: ________

FLIGHT#: ______ RUN#: ______ CONFIG: ________

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

WANDERING OF NOSE

- GOOD FEATURES

NO OSCILLATION, EASY TO GET UNDER CONTROL

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

INFLIGHT PILOT COMMENT CARD

DATE: 2 MAY OPS#: ______ PILOT: SASSCER

FLIGHT#: ______ RUN#: 56-58 CONFIG: 5-9

FEEL SYSTEM CHARACTERISTICS:

-FORCES?	LT	MED	HVY
-PITCH SENSITIVITY?	LOW	MED	HIGH

PITCH ATTITUDE CONTROL:

-INITIAL RESPONSE?		SLO	MED	FAST
-FINAL RESPONSE?		SLO	MED	FAST
-PREDICTABILITY?		NOT	SAT	EXLNT
-SPECIAL PILOT TECHNIQUES/ COMPENSATION REQUIRED?		LOW	MED	HIGH
-TENDENCY TOWARD PIO?	NO	LOW	MED	HIGH

TASK PERFORMANCE:

-AIRSPEED CONTROL?		DES	ADQ	OFF
-TOUCHDOWN ACCURACY?		DES	ADQ	OVER
-TOUCHDOWN SINK RATE?		LOW	MED	DROP
-RUNWAY ALIGNMENT?		DES	ADQ	OVER
-AGGRESSIVENESS LEVEL?		LOW	MED	HIGH
-SPECIAL CONTROL REQD IN FLARE?	NO	LOW	MED	HIGH

-REASON APPROACH ABANDONED HANDLING QUAL OR PIO? ______

INFLIGHT PILOT COMMENT CARD CONT.

DATE: ______ OPS#: ______ PILOT: ______

FLIGHT#: ______ RUN#: ______ CONFIG: ______

ADDITIONAL FACTORS: WINDS ______ / ______

TURBULENCE?	LT	MED	HVY
-LAT/DIR PERFORMANCE?	SLO	MED	FAST

SUMMARIZE EVALUATION:

- MAJOR PROBLEMS

SLOW OSCILLATION

- GOOD FEATURES

FAIRLY GOOD RESPONSE, NOT A GOOD A

REVIEW RATINGS:

-PIO? 1 2 3 4 5 6

-COOPER-HARPER? 1 2 3 4 5 6 7 8 9 10

TASK PERFORMANCE STANDARDS

DESIRED

NO PIO'S. TOUCHDOWN WITHIN 5 FT OF CENTER-LINE (MAIN WHEELS ON CENTERLINE). TOUCHDOWN AIM POINT ±250 FT. APPROACH AIRSPEED ±5 KIAS.

ADEQUATE

TOUCHDOWN WITHIN 25 FT OF CENTERLINE (TIP TANK ON CENTERLINE). TOUCHDOWN AT AIM POINT ±500 FT. APPROACH AIRSPEED +10, -5 KIAS.

APPENDIX E

NORMAL ACCELERATION TIME HISTORY WITH DIFFERENT MOTION GAINS IN LAMARS STUDY

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HAVE PIO Config. 5-10 With
"Standard" Linear Motion Gain Set

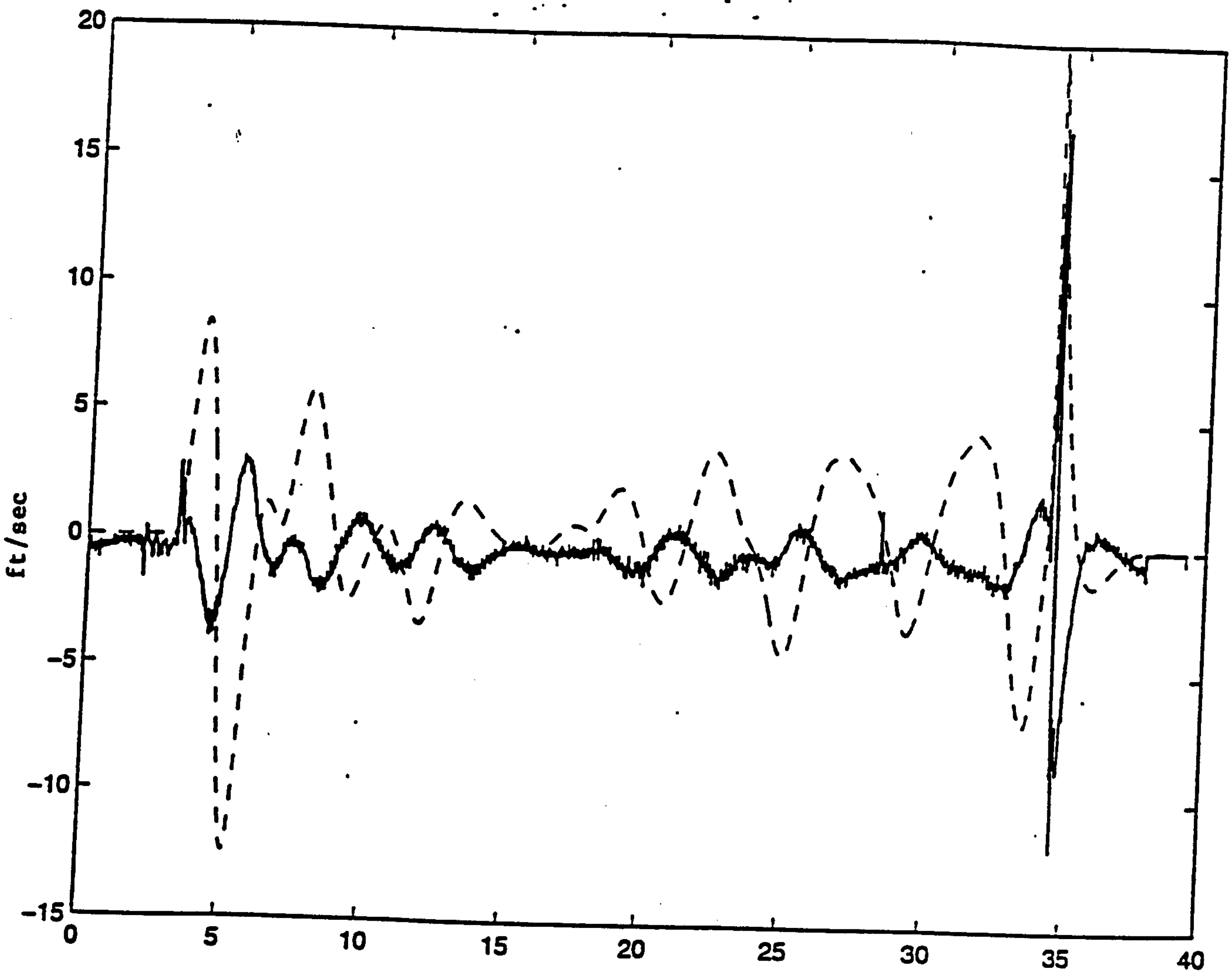

FIGURE E1

——— a_z at pilot station
- - - - a_z Model

HAVE PIO Config. 5-10 With
"Improved" Linear Motion Gain Set

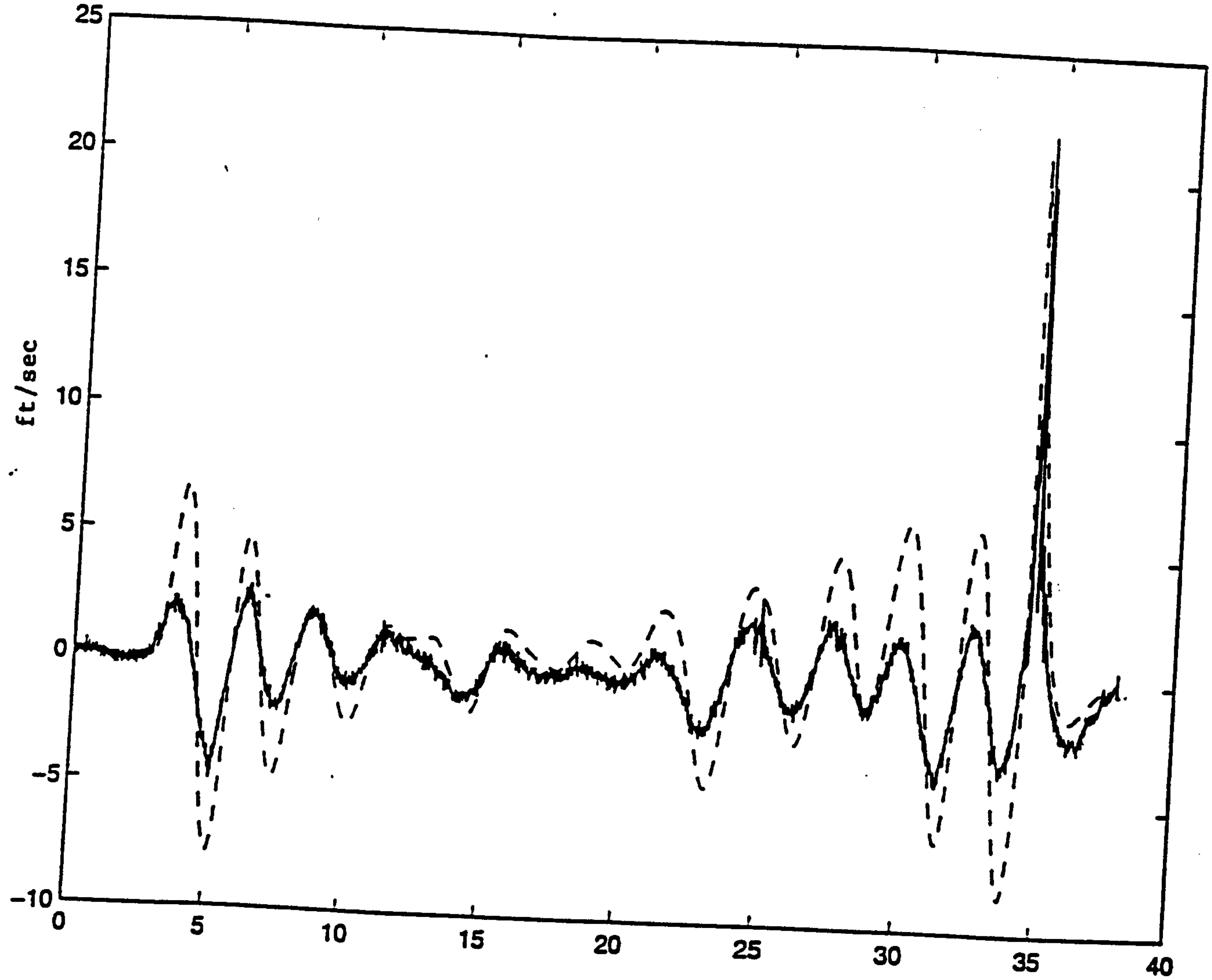

FIGURE E2

———— a_z at pilot station
- - - - - a_z Model

HAVE PIO Config. 5-10 With
"Adaptive" Motion Gain Set

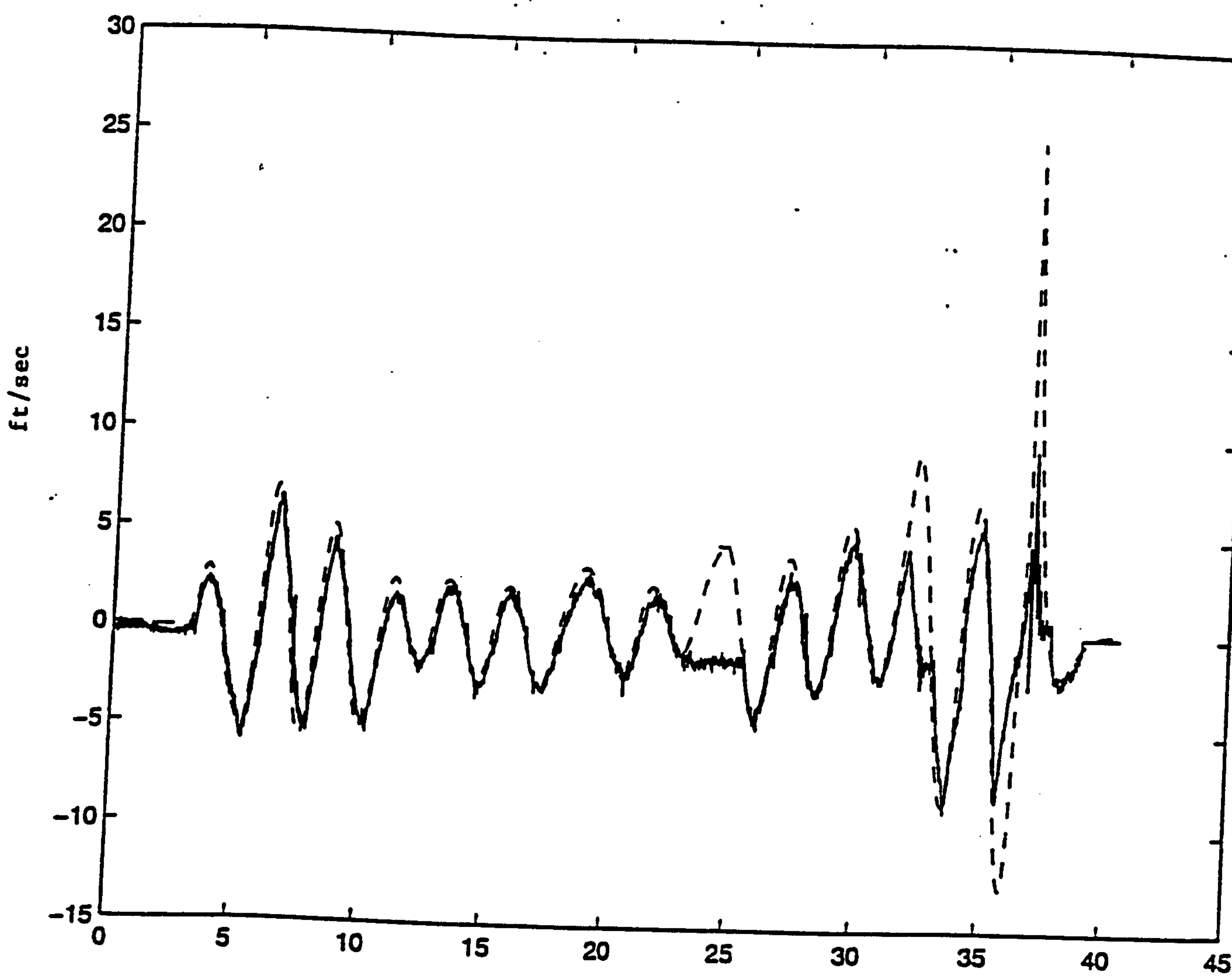

FIGURE E3

———————— a_z at pilot station

- - - - - - - - - - a_z Model

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APPENDIX F

NOMENCLATURE

Nomenclature

AFFTC	Air Force Flight Test Center
AFTPS	Air Force Test Pilot School
AGL	Above Ground Level
C-H	Cooper-Haprper
CHR	Cooper-Harper Rating
FOV	Field-of-View
g	Acceleration of gravity, ft/sec^2
Hz	Hertz
K	System gain
K_θ	Gearing
LAMARS	Large Amplitude Multi- Mode Aerospace Research Simulator
MS-1	Mission Simulator 1
MCS	Manned Combat Station
PC	Personal Computer
PIOR	Pilot-Induced Oscillation Rating
TPS	Test Pilot School

a_z	Downward (normal) acceleration of the aircraft center of gravity, g
a_{zp}	Pilot felt normal acceleration (normal acceleration at the pilot station), g
A	Coefficient of s^3 term in aircraft fourth-order characteristic equation in longitudinal axis
A_{lat}	Coefficient of s^4 term in aircraft fourth-order characteristic equation in lateral axis
A_{azp}	Coefficient of s^4 term in numerator of pilot-felt normal acceleration transfer function
A_α	Coefficient of s^3 term in numerator of angle-of-attack transfer function
A_θ	Coefficient of s^2 term in numerator of pitch angle transfer function
A_ϕ	Coefficient of s^3 term in numerator of bank angle transfer function
A_r	Coefficient of s^3 term in numerator of yaw rate transfer function
A_p	Coefficient of s^3 term in numerator of roll rate transfer function
A_β	Coefficient of s^3 term in numerator of side slip transfer function
$A_{\theta wg}$	Coefficient of s^3 term in numerator of equivalent gust command transfer function
B	Coefficient of s^2 term in aircraft fourth order characteristic equation in longitudinal axis
B_{lat}	Coefficient of s^3 term in aircraft fourth-order characteristic equation in lateral axis
B_r	Coefficient of s^2 term in numerator of yaw rate transfer function
B_p	Coefficient of s^2 term in numerator of roll rate transfer function
B_β	Coefficient of s^2 term in numerator of side slip transfer function
B_ϕ	Coefficient of s term in numerator of bank angle transfer function

Nomenclature (cont.)

B_{azp}	Coefficient of s^3 term in numerator of pilot-felt normal acceleration transfer function
B_α	Coefficient of s^3 term in numerator of angle of attack transfer function
B_θ	Coefficient of s term in numerator of pitch angle transfer function
$B_{\theta wg}$	Coefficient of s^2 term in numerator of equivalent gust command transfer function
C	Coefficient of s term in aircraft fourth-order characteristic equation in longitudinal axis
C_{lat}	Coefficient of s^2 term in aircraft fourth-order characteristic equation in lateral axis
C_ϕ	Coefficient of s^0 term in numerator of bank angle transfer function
C_p	Coefficient of s term in numerator of roll rate transfer function
C_r	Coefficient of s term in numerator of yaw rate transfer function
C_β	Coefficient of s term in numerator of side slip transfer function
C_{azp}	Coefficient of s^2 term in numerator of pilot-felt normal acceleration transfer function
C_α	Coefficient of s term in numerator of angle-of-attack transfer function
C_θ	Coefficient of s^0 term in numerator of pitch angle transfer function
$C_{\theta wg}$	Coefficient of s term in numerator of equivalent gust command transfer function
D	Coefficient of s^0 term in aircraft fourth-order characteristic equation in longitudinal axis
D_{lat}	Coefficient of s term in aircraft fourth-order characteristics equation in lateral axis
D_p	Coefficient of s^0 term in numerator of roll rate transfer function
D_r	Coefficient of s^0 term in numerator of yaw rate transfer function
D_β	Coefficient of s^0 term in numerator of yaw rate transfer function
D_{azp}	Coefficient of s term in numerator of pilot-felt normal acceleration transfer function
D_α	Coefficient of s^0 term in numerator of angle-of-attack transfer function
E_{lat}	Coefficient of s^0 term in aircraft fourth-order characteristics equation in lateral axis
F_{as}	Roll control stick force, positive right, lb
F_{es}	Pitch control stick force, positive aft, lb
F_{rp}	Rudder pedal force, positive right, lb
l_x	Pilot's location forward of the aircraft center of gravity, feet
I_{xx}	Aircraft moment of inertia with respect to the x-axis (slug-ft^2)
I_{yy}	Aircraft moment of inertia with respect to the y-axis (slug-ft^2)
I_{zz}	Aircraft moment of inertia with respect to the z-axis (slug-ft^2)
I_{xz}	Aircraft moment of inertia with respect to the x-z plane (slug-ft^2)
$L'_{\delta a}$	Modified stability derivative, roll acceleration due to aileron (sec^{-2})

L_p	Stability derivative, roll acceleration due to roll rate (sec^{-1})
L'_β	Modified stability derivative, roll acceleration due to side slip (sec^{-1})
L'_p	Modified Stability derivative, roll acceleration due to roll rate (sec^{-1})
L'_r	Modified stability derivative, roll acceleration due to yaw rate (sec^{-1})
$M_{()}$	$=[1/I_y][\partial M/\partial ( )]$, body axis dimensional moment derivative, rad/sec^2 per ( )
M_q	Stability derivative, pitch acceleration due to pitch rate (sec^{-1})
M'_q	Modified stability derivative, pitch acceleration due to pitch rate (sec^{-1})
M_u	Stability derivative, pitch acceleration due to forward velocity (1/ft-sec)
M_w	Stability derivative, pitch acceleration due to vertical velocity (1/ft-sec)
$M_{\dot{w}}$	Stability derivative, pitch acceleration due to vertical acceleration (ft^{-1})
M'_w	Modified stability derivative, pitch acceleration due to vertical velocity (1/ft-sec)
$M_{\delta e}$	Stability derivative, pitch acceleration due to elevator deflection (sec^{-2})
N/α	Steady-state normal acceleration per angle-of-attack (g/rad)
$N^{azp}_{\delta e}$	Numerator of pilot-felt acceleration to the elevator deflection transfer function
$N^{\alpha}_{\delta e}$	Numerator of angle-of-attack to the elevator deflection transfer function
$N^{\theta}_{\delta e}$	Numerator of pitch angle to the elevator deflection transfer function
N^{θ}_{wg}	Numerator of pitch loop equivalent gust transfer function
$N^{\phi}_{\delta a}$	Numerator of bank angle to the aileron deflection transfer function
$N^{r}_{\delta r}$	Numerator of yaw rate to the rudder deflection transfer function
$N'_{\delta a}$	Modified stability derivative, yaw acceleration due to the aileron deflection (sec^{-2})
$N'_{\delta r}$	Modified stability derivative, yaw acceleration due to the rudder deflection (sec^{-2})
N'_r	Modified derivative, yaw acceleration due to yaw rate (sec^{-1})
N'_β	Modified derivative, yaw acceleration due to side slip (sec^{-1})
N'_p	Modified derivative, yaw acceleration due to roll rate (sec^{-1})
q	Perturbation pitch rate referenced to the vehicle body axis (1/sec)
Q	Total pitch rate referenced to the vehicle body axis (1/sec)
$\dot{Q}$	Total pitch acceleration referenced to the vehicle body axis ($1/sec^2$)
u_o	Trim forward speed referenced to the vehicle body axis (ft/sec)
u	Perturbation forward velocity referenced to the vehicle body axis (ft/sec)
U	Total forward velocity referenced to the vehicle body axis (ft/sec)

Nomenclature (cont.)

$\dot{U}$	Total forward acceleration referenced to the vehicle body axis (ft/ sec^2)
w_o	Trim downward speed referenced to the vehicle body axis (ft/sec)
w	Perturbed downward speed referenced to the vehicle body axis (ft/sec)
$\dot{w}$	Perturbation vertical acceleration referenced to the vehicle body axis (ft/sec^2)
W	Total vertical velocity referenced to the vehicle body axis (ft/sec)
$\dot{W}$	Total vertical acceleration referenced to the vehicle body axis (ft/ sec^2)
p	Perturbation roll rate referenced to the vehicle body axis (1/sec)
P	Total roll rate referenced to the vehicle body axis (1/sec)
$\dot{P}$	Total roll acceleration referenced to the vehicle body axis (1/sec^2)
r	Perturbation yaw rate referenced to the vehicle body axis (1/sec)
R	Total yaw rate referenced to the vehicle body axis (1/sec^2)
$\dot{R}$	Total yaw acceleration referenced to the vehicle body axis (1/sec^2)
v	Perturbation side velocity referenced to the vehicle body axis (ft/sec)
V	Total side velocity referenced to the vehicle body axis (ft/sec)
V_{to}	Total initial velocity (ft/sec)
$\dot{V}$	Total side acceleration referenced to the vehicle body axis (ft/sec^2)
$\dot{X}$	Rate of change of forward component of aircraft position to the vehicle body axis (ft/sec)
$\dot{Y}$	Rate of change of side component of aircraft position (ft/sec) to the vehicle body axis (ft/sec)
$\dot{H}$	Rate of change of vertical component of aircraft position (ft/sec) to the vehicle body axis (ft/sec)
s	Laplace transform variable
$1/T_{\theta 1}$	Low frequency pitch attitude zero (sec^{-1})
$1/T_{\theta 2}$	High frequency pitch attitude zero,(sec^{-1})
$X_{()}$	=[1/m][$\partial X/\partial$ ( )], body axis dimensional X force derivative, ft/sec^2 per ( )
$Z_{()}$	=[1/m][$\partial Z/\partial$ ( )], body axis dimensional Z force derivative, ft/sec^2 per ( )
$z_{\dot{w}}$	NT-33 modified z_q derivative
α	Perturbed angle-of-attack referenced to the vehicle body axis system (deg)
β	Perturbed side slip angle referenced to the vehicle body axis system (deg)
Δ, Δ_{lat}	Characteristic equation
ω_d	Dutch roll natural frequency (rad/sec)
ω_{n1}	Natural frequency, second-order flight control system (rad/sec)
ω_{n2}	Natural frequency, fourth-order flight control system (rad/sec)
ω_p	Phugoid mode natural frequency (rad/sec)

Nomenclature (cont.)

ω_r	Center frequency of pitch attitude closed-loop pilot-vehicle system (rad/sec)
ω_{sp}	Short period mode natural frequency (rad/sec)
ω_a	Natural frequency of the actuator (rad/sec)
$\lvert\phi/\beta\rvert_d$	Absolute value of control fixed roll-to-side slip ratio at ϕ_d
τ	Pilot time delay in the θ/F_s loop, sec
τ_a	Pilot time delay in the a_{zp}/F_s loop, sec
τ_e	Pilot equivalent time delay in the θ/F_s loop, sec
τ_p	Phase delay (sec)
τ_r	Roll mode time constant (sec)
τ_s	Spiral mode time constant (sec)
$\tau_{\theta 1}$	Low frequency mode numerator time constant, θ/δ_e (sec)
$\tau_{\theta 2}$	High frequency mode numerator time constant, θ/δ_e (sec)
τ_1	Numerator time constant for first-order flight control system (sec)
τ_2	Denominator time constant for first-order flight control system (sec)
θ	Perturbed pitch angle referenced to the vehicle body axis system (rad)
θ	Time rate of change of pitch angle referenced to the vehicle body axis system (rad/sec)
θ_0	Equilibrium pitch angle (rad)
ϕ	Bank angle referenced to the vehicle body axis system (rad)
Ψ	Yaw angle referenced to the vehicle body axis system (rad)
ζ_d	Dutch roll mode damping ratio
ζ_p	Phugoid mode damping ratio
ζ_{sp}	Short period mode damping ratio
ζ_1	Damping ratio, second-order flight control system
ζ_2	Damping ratio, fourth-order flight control system
e_1, e_2, e_3, e_4	Quaternions
$\dot{e}_0$	Time derivative of ( ) quaternion (sec^{-1})
$\ddddot{\delta}_c$	Fourth state of the fourth-order flight control transfer function
$\dddot{\delta}_c$	Third state of the fourth-order flight control transfer function
$\ddot{\delta}_c$	Second state of the fourth-order flight control transfer function
$\dot{\delta}_c$	First state of the fourth-order flight control transfer function
δ_c	Control command
$\ddot{\delta}_0$	Second state of the ( ) transfer function
$\dot{\delta}_0$	Second state of the ( ) transfer function
$\delta_{()}$	State of the ( ) transfer function
δ_e	Elevator deflection (deg)

Nomenclature (cont.)

δ_a	Aileron deflection (deg)
δ_r	Rudder deflection (deg)
δ_{as}	Roll stick deflection, positive right (inches)
δ_{es}	Pitch stick deflection to actuator, (deg.)
δ_{rp}	Rudder pedal deflection, positive right (inches)
δ_{ec}	Pitch stick input to flight control system, positive aft (inches)